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THE CHEMISTRY

OF

VEGETABLE & ANIMAL PHYSIOLOGY

THE CHEMISTRY

OF

VEGETABLE & ANIMAL PHYSIOLOGY

Gerardus Johannes

BY G. J. MULDER

PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF UTRECHT

TRANSLATED BY DR P. F. H. FROMBERG; WITH INTRODUCTION AND NOTES BY JAMES F. W. JOHNSTON, F.R.S.S. L. & E., &c.

WITH TWENTY ILLUSTRATIONS, COLOURED AND PLAIN

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INTRODUCTION.

THE name of MULDER is now familiar to most of the readers of works on animal or vegetable physiology. The publication of the successive parts of the present volume has been one of the means by which the distinguished Dutch chemist has been most widely *introduced*, and his opinions most fully made known to English readers.

When the first part issued from the press, I proposed to write a more lengthened introduction to the finished work than is now necessary. At that time the waters of chemical strife had been stirred up and much troubled. An unnatural, and in some respects unworthy, excitement had found its way into the crucibles and ink-stands of Giessen, and Liebig and his pupils, like the wandering knights of old, were shivering their lances against every one they met. That strife has now died away, and a calm has ensued more favourable not only to the prosecution, but to the discovery of truth. It is on the return of this calm that I have the pleasure of presenting the following work in a more perfect form to my scientific countrymen.

As in all works which pretend to completeness upon any branch of the sciences of observation, there is of

course much in this volume which has been derived from other sources; but the reader who shall carefully study it, will agree with me in opinion, that few books have appeared in our day which are so full of new matter. New thoughts—original views—speculations calmly, thoughtfully, and cautiously put forward—elaborate researches, analytical and microscopical — criticisms truthful, discreet, and searching—occupy a great portion of its pages. While I by no means agree with all the opinions it embodies, and have occasionally, in brief notes, ventured to express my dissent, yet the general character of the book is such that I feel myself under a personal obligation to the publishers for enabling me to add it to our English scientific literature.

The *first* part is occupied with preliminary considerations on chemical and organic forces—a part of the book which many will find hard to read, but which will abundantly repay the thoughtful student of molecular chemistry. It includes, also, a view of the general relations of the air, water, and soil, to organised beings.

The *second* part contains the chemical history of the various substances—proximate principles, as they have been called by some — which compose the bulk of animals and plants. In this part also—as where the author treats of chlorophyle, protein, and gelatine—the reader will find much to interest him.

The *third* part treats of those constituents of the organised kingdom which possess peculiar forms. The tissues and structures of animals and plants are described chemically and microscopically. It is, for the most part, filled with the details of observations with

the microscope, made by Mulder himself, upon the forms and chemical characters of the tissues and other organised parts of animals and plants. It is illustrated with twenty beautiful plates, illustrative of these tissues, many of them beautifully coloured, to show the nature of the reactions produced upon the several tissues by various chemical agents. This part forms a valuable addition to our still infantile chemico-histological knowledge.

The *fourth* part is devoted to the food and nutrition of plants. It discusses, first, the absorption of food by plants, and the mode in which it is transmitted upwards and downwards; and next, the transformations which this food undergoes in the various portions of the plant to which it is carried. This part addresses itself more especially to the chemist, and to the chemical and general physiologist.

I think it unnecessary now to do more than express my regret that the appearance of the work, in this more complete form, should have appeared to linger so long. Perhaps the constitutional slowness ascribed to his country has not been without its influence even upon the genius of Mulder, and has stood in the way of the more rapid diffusion of the new ideas which his work contains—perhaps the aiming after greater perfection and completeness, which sometimes becomes almost a disease in great minds, has retarded the completion of his book; but no retarding cause which has allowed opinions to be more fully thought out, and researches brought nearer to a close, ought to be seriously complained of by the lover of truthful knowledge. I con-

fidently anticipate, therefore, that it will now find a place in the library of every accomplished chemist or physiologist—of every one who wishes to possess the means of becoming acquainted with the actual state of our knowledge upon the subjects on which it treats—of understanding and being able to weigh the reasons which can be advanced in favour of opinions in chemical physiology at present either generally received, or more or less doubted and in dispute.

JAMES F. W. JOHNSTON.

DURHAM, *March* 1849.

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THE CHEMISTRY

OF

VEGETABLE AND ANIMAL PHYSIOLOGY.

CHAPTER I.

CHEMICAL AND ORGANIC FORCES.

In the doctrine of life, no position has been more strenuously maintained, than that a peculiar force exists by which organic substances are governed, by which they are arranged in certain specific modes, and are enabled to assist in sustaining the living system, and to create a chain of phenomena, which as a whole are called *phenomena of life*. This vital force has been described as one quite peculiar, of which not the slightest trace is to be found in inorganic nature. Organic and inorganic nature are often indeed contrasted. We hear of the animate and inanimate forces of nature; we used to shrink from observing any connexion between them; and, in particular, it was thought that the endeavour to explain many phenomena of life by means of the so-called dead forces might detract from the doctrine of life.

In the true study of nature the principal aim ought to be, not only to make ourselves acquainted with the phenomena

and laws, which distinguish and regulate living and dead matter, but also to arrange those phenomena and laws, and exhibit them in their several relations. The more our knowledge of these two departments is extended, and the nearer the several parts of the great science of nature are seen to approximate, the more firmly must we embrace the idea, as necessarily conformable to truth, that the same forces govern alike the animate and the inanimate kingdoms.

Those who proceed on the assumption, that no such connexion exists, will certainly not be able to trace it; but a search, conducted with impartiality, will be rewarded with the discovery of as much as may exist.

In the natural sciences, the words *matter* and *force* are continually recurring. We endeavour, by an effort of imagination, to separate the one idea from the other. Yet we cannot conceive of matter without force, and scarcely of any force which does not react upon matter. We encounter many difficulties, while attempting to penetrate into the properties of matter. We are perplexed, first, with its being divisible either finitely or infinitely; secondly, with the great diversity of substances which exist; thirdly, with the great number of elementary bodies now known to chemists.

Then the idea expressed by the word *atom* is by no means distinct, though the term must frequently occur in treating of natural philosophy.

In the natural sciences, we do not seek to go beyond the knowledge which is acquired by observation and by the comparison of visible objects, and thus we avoid that labyrinth, in which many of the wise and learned have, both in former and later times, involved themselves, by clinging to abstract ideas borrowed from the visible world. We acknowledge material diversity because we observe it; we acknowledge a great number of elements because we see them; we do not meddle with the term *atom*, but substitute for it, wherever we can, the more comprehensive and intelligible expression—*equivalent*.

In the natural sciences, *force* is used to signify an assumed cause of observed phenomena; we therefore do not observe forces, but suggest their existence to ourselves; and we do so in

conformity with sound principle, for the phenomena constrain us to presume that such forces exist. No cautious inquirer into nature goes farther in the present day; we do not introduce forces, to which we assign properties; but we form the idea of some particular force, after the necessity for its existence is demonstrated by the observation of natural phenomena. The idea of force is therefore a concrete one, by which every speciality in the phenomena is embraced, and unity is given to the whole.

Such are the simple principles by which we are, in the present day, guided in our inquiries. The forces of nature, which we recognise, are of such a number and kind as we learn from the phenomena they ought to be; and the error, so prevalent in former times, of attributing properties to forces without previously proving, from observation, that those properties existed, is now carefully avoided.

Proceeding from this point of view, we propose to make some observations on the organic and inorganic forces of nature, sometimes called the living and dead forces. These observations will not add anything to the amount of our scientific knowledge, but may serve to explain and establish the proposition that a connexion exists where hitherto it has, erroneously as I think, not been recognised.

It is scarcely necessary to observe that the expression *dead force*, when used to denote the operating causes in inorganic nature, has no substantial value. Still, it is understood to signify the force of dead nature, in opposition to that of living nature, where a particular series of phenomena appears; and this is the meaning in which we use the expression.

The chemistry of the present day, which occupies itself specially with the doctrine of molecular forces, perceives peculiar causes, operating in the small particles of matter. Our inquiries may not inappropriately be commenced with the investigation of this subject, the study of which is the foundation of any knowledge we acquire in regard to organic forces; for no organism is composed of materials which are not subject to the laws of those chemical forces, which are proper to chemical substances.

While, however, we would endeavour to show that in the living organism the same molecular forces operate as efficient causes, we are not to be understood as holding, that they are combined with consciousness or the more elevated rational principle.

I will not venture to raise the veil, by which the action of the nerves, and still more the higher functions of the mind, have hitherto been shrouded from our observation. As man has an immaterial and immortal part, which is identical with his real being, and of which alone he will consist, when the material frame by which he is bound to the earth shall be dissolved; and as the inferior animals possess, in common with man, certain powers of perception, associated with certain appropriate organs, whose functions have no connexion with consciousness; so do animals and plants perform in common a great many operations which are distinct from both of those now mentioned, or which at least have their origin in different causes.

It is only the latter class of which I speak, and to which I apply the general term of organic life. To that subject I shall restrict my remarks.

It is well known that, in animals, such operations are performed through the agency of the nerves, and in them, therefore, are generally more complicated than in plants. The similarity of the operations themselves, however, intimates the existence of a connexion between the causes from which they respectively arise. But the nature and strength of this connexion are and will continue to be an enigma, as much as the action of the nerves itself. The peculiar nature of organic life—the difference between living nature and what is called dead nature—is, however, not determined by the action of nerves. The properties common to animals and plants will be treated of exclusively; these properties being included in the general idea of functions of life. In the first place, we shall review, in succession, the properties of the elements, which enter into the composition of all that exists in nature.

We shall be the first to admit the force of the objection,

with which we may be met, that it is more easy to pull down than to build up. Science has not yet made such progress as to enable us, from a more elevated point of view, to take a comprehensive survey; but this will never afford a rational ground for adhering to incorrect propositions. The suggestions which follow are therefore to be regarded as thrown out only for consideration. They will require to be much more fully developed before they can pretend to form a complete system.

§ 1. Chemical Forces.

We see in all the elementary substances, without exception, a disposition to combine with each other, and we therefore form the idea that a force exists in them, which is called *the force of affinity*. We see this combination effected; and infer, that there necessarily exists in substances a cause of the property, which they possess, of uniting together. There is no element which cannot be united with others; there is none, therefore, which is destitute of that property in a greater or less degree. The power of combination is thus a property of matter, produced by a force, to which every material thing is subject, whatever its name may be, or to whatever part of nature it belongs.

We observe, however, in the elementary bodies many other properties besides that of uniting together. It would not be a simplification of science to assign a specific force to each effect produced by these elementary bodies; but it is impossible to have an accurate idea of any element, if we think of it only as impenetrable and ponderable, extended and in substance different from every other, indivisible and endowed with a tendency to combine with other elements. If we do not go further, how should we be able to form a conception of isomorphism and of isomeric combinations—of the distinct character which belongs to each elementary body, as compared with others—of their dynamical differences? We are too much accustomed to confine our attention to the sensible properties of matter. We speak of copper and mercury as red

and white, solid and fluid, fixed and volatile, and we dwell too much upon these and similar physical differences. We do not sufficiently inquire why the one forms combinations with different quantities of the same substances, accompanied with entirely different phenomena, as contrasted with those combinations which are formed by the other. We arrange the elements in groups, in so far as they agree in some of their properties; but we do not investigate, in the first place, the cause why such agreement is exhibited by some, and why the opposite is exhibited by others. How do we account for the great difference between the two metals sodium and platinum? The one cannot combine directly with oxygen, though the other does, exhibiting at the same time very interesting phenomena. Sodium shows itself active in all circumstances; platinum is generally passive, and incapable of producing any marked phenomena. We say that sodium has a greater degree of affinity; but we derive the idea of affinity from observing the production of a combination—the final result of the power which is lodged in the sodium. When water is violently decomposed by it, this effect ought undoubtedly to be ascribed to the power possessed by sodium of combining with oxygen; but is this combination produced by nothing but the attraction between sodium and oxygen? We do not see any of these phenomena produced by general or physical attraction, and we must therefore superadd something to the idea of attraction to constitute what we understand by affinity. The question arises, whether the attraction by affinity operates in certain definite and invariable proportions? This consideration is necessary to an accurate notion of affinity; but it does not comprehend all that requires solution. It does not explain anything as to the differences among bodies in regard to their colour, smell, and taste; their being solid, fluid, or gaseous, fixed or volatile; their boiling point, density, specific heat, atomic weight;—nor anything in regard to isomorphism, to isomerism, or the evolution of heat, light, and electricity in chemical combinations;—nor any thing respecting the singular quality, which each element possesses, of forming 1, 2, 3, and so on to the number of 7, combinations

with another element, in certain invariable proportions—combinations which are formed from the same two elements, under conditions, which differ from each other only in a small degree.

If we consider the molecular forces in elementary bodies only as producing combinations between molecules of dissimilar kinds, the idea at which we arrive is limited and unproductive, and we overlook a long series of singular phenomena, which cannot be reduced to that principle.

The observation and arrangement of phenomena, the investigation of the laws which regulate them, and the ascribing to bodies of powers which are in accordance with the character of the phenomena dependent upon them, are all required for a correct knowledge of nature. In the present condition of chemistry, we are obliged to form a more distinct idea of the forces by which the molecules of matter are governed, than was sufficient in former times; because we know, with positive certainty, that there is nothing in common between the quality of the matter in one element and the quantity of another combined with it; and also, that the crystalline form of the compound is independent of the quantity also. Sulphur, selenium, chromium, and manganese, bodies of very different natures, take each three equivalents of oxygen (O^3), and yield with bases salts of the same crystalline form. The sulphates, seleniates, chromates, and manganates are all isomorphous. And so with a great many other elementary substances.

The conclusion which we draw, therefore, is legitimate,—that there are certain analogous powers present in sulphur, selenium, chromium, and manganese; and thus we arrive at the idea, that the chemical relations of these elements are not dependent upon their matter, but upon the analogous forces by which their molecules are governed. Thus the idea of the matter of sulphur is associated with somewhat of the idea of force, and of the same force which operates in selenium also—which operates not only in forming combinations, but in contributing also to the formation of the whole character of the compound substances produced. We remark

the effects of this force which exists in sulphur, selenium, &c., even in more complicated compounds than those to which we have referred. Sulphate of soda and seleniate of soda, for instance, are both efflorescent salts, and both possess the singular property of being more easily soluble in water of 33° Centigrade (=91½° Fahr.) than in water of 100° Cent. (=212° Fahr.),—a property which is rare in the highest degree, and which does not depend here on the substance of sulphur or selenium, but on the similar molecular forces, by which both sulphur and selenium are governed. Phosphorus and arsenic are isomorphous. Both combine with oxygen, and form acids, whose composition is represented by RO^5. Each of these acids forms with soda two analogous salts. All the four salts contain one equivalent of acid, two of base, and one of basic water; but one phosphate and one arseniate contain in addition 24, the other phosphate and arseniate only 14, atoms of water of crystallization.[1]

If, in the same manner, we pass in review the whole series of the elementary bodies; if we consider them abstractly from their matter, then we recognise innumerable modifications of those molecular forces, in the phenomena which each of them exhibits. These forces are often exercised in the production of chemical combinations, but this is by no means their sole characteristic.

The combination of two or more elements into one whole is the best known effect of all the existing molecular forces. And the phenomena which we observe during this combination of substances, and the results of such combination, have enabled us to form a definite idea of a cause adequate to produce them. The combination is attended with phenomena which can be traced, and the results of which can be measured and weighed. We must be content with having reached this point, and can only hope that the time will yet arrive,

[1] The fact here stated is represented by the following general expression:—

$$2\dot{N}a + \dot{H} + \left\{\begin{matrix}\cdot\cdot\\ \cdot\\ \cdot\cdot\\ As\end{matrix}\right. + \left\{\begin{matrix}14Aq\\ 24Aq\end{matrix}\right.$$

when we shall be able to form more just conceptions of the other forces by which the molecules are governed. We can scarcely, as yet, give a name to the science of this subject—a science which appears to be actually boundless in extent.

The effect which we call affinity, is to be ascribed to a power of mutual chemical attraction, which dwells in the elementary bodies. Before such a combination is completed, and before they come into contact, they must possess a power, by which they are enabled to effect the combination *at a fitting time*, or they must acquire this power *as soon as they touch each other*. Here it is difficult to choose our way; but it does not seem impossible. So far as the idea refers to the excitation of force, the principle is the same as that of electricity, which is an operating cause also present in the molecules; but though it be so, yet it is not identical with the force of affinity.[1]

If we touch a piece of wood with a pen, we observe no sign of combination; but when antimony and chlorine come into contact, they unite immediately; and the wood does not possess any power of exciting in the pen a combining force, neither has the pen any power of doing so in the wood. The chlorine, on the other hand, has the power of exciting a force of combination in the antimony; and the antimony of doing so in the chlorine. Now, it is a matter of indifference, whether we conceive that the forces slumber in the antimony and the chlorine, and are brought into operation by contact; or that those forces were, previously to contact, present in the two bodies in an active state, but produced the phenomena of combination only during the contact. These two ideas may be reckoned of equal value for scientific purposes; because the power, exerted by the chlorine, of exciting the slumbering forces in antimony, and the similar power exerted by the antimony upon the chlorine, must undoubtedly, one or both, pre-exist before contact; if not so, then two slumbering forces are excited by each

[1] We cannot, of course, attempt here, however briefly, to indicate in what respects the forces of affinity and electricity either coincide or differ.

other, which is absurd. Whatever excites action we call force. Chlorine excites action in antimony, and antimony in chlorine; so that before contact a power exists either of *excitation* or of *combination*,—and that, if not in both, at least in one of these bodies. The mode of considering this point is almost a matter of indifference; but we must always bear in mind that it is a power, a force which is exerted by the one, and which acts upon the other. This force, I repeat, must exist in one of the bodies before contact; and may be called its *chemical tendency*. It manifests itself *during* contact, but cannot be produced *by* contact, any more than electricity or other forces. We cannot conceive of a force being produced *by* contact. Contact is a condition to which substances must be subjected, in order that some phenomenon may be produced; as touching the ground with the feet is a *condition* required to enable us to walk. A *condition* necessary to any phenomenon differs entirely from a source of action, from the cause of the phenomenon; and the theory of contact, therefore, seems to me impossible and absurd, at least in the sense in which it has been so often maintained.

We are conducted by the phenomena to the recognition of a power in substances, which can be excited under certain circumstances, and which is capable of producing a combination. This power necessarily *exists* before it is excited, and often requires only the *contact* of substances to allow the phenomena, called *combination*, to be produced. According to our view, therefore, we must suppose a power in *all* the elements, either of exciting or of exhibiting a force which causes a combination. This is what we call *chemical tendency*.

This power varies greatly in different elements. It varies in respect, first, of quantity, and secondly, of quality.

Those elements only which have the same atomic weight attract an equal quantity of the same element, while all the other elements, with but a few exceptions, attract very different quantities. There is also a very considerable variety in their mode of combining with other bodies; the phenomena which they produce are very different, and there is especially a great diversity in their power of combining, in one or more

proportions, with another element. How is this latter difference caused, if not by the difference in their combining quantities, and by the special nature of their chemical tendencies? For (with the exception of the isomorphous bodies, and those which have the same atomic weight) every elementary body has its own peculiar qualities, and its own combining quantity, showing that the substances are specifically distinct. Each element also might be made to appear in a specific form, though they be all derived from the same base, because every one of them is governed by specific forces; in other words, a different distribution of the chemical tendency in an element would be sufficient, to make the same element appear specifically different.

But, however this may be, either one and the same principle, differing from all others, not materially but dynamically, may be the base of all the elements, or there may be as many elements as there are groups of isomorphic substances, or as many as are designated, in the chemistry of the present day, elementary bodies. This question cannot yet be determined. Adhering to what we observe and know with certainty, we conclude that every elementary body is endowed with a great many specific properties, which, to a large extent, are dependent on the same principle that causes their combination, and thus on the proportion and character of the chemical tendency.

If we adopt this idea, we have the advantage of seeing somewhat of vitality, energy, and activity in dead matter. It is an idea, derived from the endless series of phenomena which are observed in the laboratory, in daily occurrences, and in nature at large. This series of phenomena, exhibiting the effects of that diversified chemical tendency in bodies, which is already observed in science, is fitted to excite admiration. Elementary works are filled with descriptions of substances which exist in consequence of that tendency, and the chemist cannot see the end of that series of new combinations which are continually formed by these substances, as so many results of the primitive forces. With such an idea we do not confine ourselves exclusively to the material cha-

racter of each element; for in this way we could not attain to a correct, certainly not to a practical, conception of this subject, inasmuch as this material character presents a union of the physical properties of bodies, and not of those properties by which the elements appear capable of producing phenomena.

If the question be raised, whether the introduction of this idea will produce immediate fruits, we must reply in the negative. Hitherto the subject has not been studied from this point of view, and science is not yet supplied with sufficient data to allow of its being so studied. To view it, however, in this light, may be considered as an attempt to find a better way.

Four of the elements have a wholly peculiar character; all the others are more or less limited in their capacity of mutual combination, while carbon, hydrogen, nitrogen, and oxygen are apparently unlimited in this respect. We may modify, in almost innumerable ways, the quantity and quality of the affinity found in these four elements. For that reason they deserve a prominent place in chemistry. Lead and oxygen combine in two proportions only, the protoxide PbO, and the peroxide PbO^2, and these unite to form a third combination (red lead); but the combinations of carbon and hydrogen are innumerable, and differ not only in relative but also in absolute quantities. We have not only the series, CH, CH^2, &c., but also C^2H^2, C^4H^4, &c. The combination C^5H^4 is also inexhaustible, either in the simpler form of C^5H^4, or as $C^{10}H^8$, $C^{15}H^{12}$, $C^{20}H^{16}$, &c. We know a combination, C^2H; another C^4H^3, another C^4H^5, &c.—and so with C and N, N and H, and CNH and CNO, CHO and CHNO. In one word, though these four elements have a great many properties in common, they exist as a distinct group, supplied with forces of affinity which are susceptible of infinitely more modifications than those which are present in the other elements. We now proceed to examine somewhat more closely the character of the chemical combination of elementary bodies.

4. Determinate value of the forces which produce combination. Apparent quiescence of the forces during combination.

The simple substances differ in their power of mutual combination. They differ, therefore, in respect of the several forces which cause this combination, or in the capacity of having those forces excited in peculiar circumstances. The substances, which seem to possess this tendency at every temperature, are potassium, sodium when combining with oxygen, chlorine when combining with a great many metals, &c. This tendency is peculiar to these substances, and, according to our observation, it is correct to say, that there exists in potassium, independent of circumstances, a tendency to combine with oxygen, and in oxygen a tendency to combine with potassium.

This tendency is clearly characterised by its operating between molecules of different kinds at distances too small to be measured, and by its producing from these a combination in a fixed proportion.

If substances chemically different yield to this tendency, a combination of two unlike bodies results,—an intimate union, in which each new molecule is composed of the two combined. A mass of potassium does not possess this power as a mass. It is peculiar to its small particles. The smaller even those particles are, the more easy is their combination.

This peculiar power in potassium of attracting oxygen, and in oxygen of attracting potassium, thus resides in the most minute particles; that is to say, in those which we can divide no further. The two particles now closely approximate each other, and present new properties, which are chiefly dependent on the character of the combined substances, but result in part also from the forces by which those substances are governed.

After the combination is completed, the power of uniting still further with oxygen, at least under the same circumstances, is lost to the potassium. The two molecules have wholly satisfied their desire of combination, and the two opposite forces have therefore made each other quiescent, either partly or wholly. If they have made each other

wholly quiescent, the new substance cannot combine further with any other. But if the force in potassium (K) be not wholly counterbalanced by the force in oxygen (O), more or less of (K) remains in the combination, and *vice versa* with (O). It seldom happens that the two forces entirely counterbalance each other; but, in general, an excess of the one or of the other remains, which appears externally, and impresses on the combination a character conformable to that which is proper to the predominating element.

The constancy of the proportions in which the elements combine with each other, proves that the forces are of equal value in determinate circumstances. The cause of this constancy cannot be traced to one of the combined substances only, but it must be present in both, so as to complete the combination, of which the principal characteristic is a perfect constancy of quantities. While the combination is in progress, the sensible action of quantities of equal amount is apparently annihilated. If we suppose, for instance, that oxygen has a force of affinity of 3(O), and potassium of 6(K), 3(K) must necessarily remain after their combination, in certain circumstances, whilst 3(K) and 3(O) make each other quiescent.

This is proved by observation. Potash is not inactive, but possesses in its turn a tendency to combine with other substances, which, though less powerful than that of potassium, operates in the same manner; thus there is a quantity of chemical tendency, which has not passed into a state of rest, whilst the metal was combining with oxygen. We would call the remaining part of this force in potash 3(K).

Sulphur and oxygen (S and O) combine with each other, when favoured by peculiar circumstances, in the same manner as potassium and oxygen combine at the common temperature. It is thus indispensable to this union that sulphur should have a certain quantity of force, which disposes it to combine with oxygen and produce sulphuric acid, and *vice versa*. By this combination the whole quantity of the opposite forces, or a part of either, is again apparently lost; and then some of the force, either of the oxygen or of the sulphur, remains. If we sup-

pose that the forces by which oxygen and sulphur (O and S) operate upon each other, have the proportion of 3(O):1(S), we have remaining 2(O) after the combination of O and S into SO^3.

Potash, therefore, retains a force of 3(K), and sulphuric acid of 2(O). According to this view, neither potash nor sulphuric acid is neutral, but they are both still supplied with forces of affinity opposite to each other, so that they are able to produce a new combination of the substances already in composition; that is, of the sulphuric acid and the potash into sulphate of potash. As soon as these combine with each other, potassium (K) is again neutralized by oxygen (O). If we assume that of the 3(K) and 2(O), 2(K) are counterbalanced by 2(O), there remains 1(K) after sulphate of potash has been produced.

In this sulphate of potash, two forces, opposite to two others, are thrice enveloped; two of them in the elements of the potash, two in the elements of the sulphuric acid, and two in the elements of the sulphate of potash. These forces counterbalance each other; the feebler of them, (O), has been made imperceptible, but the stronger of them, (K), is able to act on other substances, through the force which remains active after the oxygen has been neutralized.

In our example, 1(K), or, in other words, one quantity of the force originally present in potassium, still remained after the combination of SO^3 with KO. Sulphate of potash, therefore, is also not neutral, but may combine anew with other substances, and especially with those, which contain oxygen (O) once, twice, or more times. Supposing we have such a substance in sulphate of alumina, we see alum formed on the same principles, by the combination of the sulphate of alumina with the sulphate of potash. Thus it appears that the same force originally residing in the elements, is capable of producing all the chemical combinations of the first, second, and third orders.

The value of the forces, which are originally involved in the elements, is still undetermined. In course of time, however, it will be ascertained. The quantities, which we have

assumed merely to explain our views, must therefore not be regarded as having a real value. It is, however, certain that there must always be two forces of opposite character, where attraction and combination are the effects.

This mutual combination does not take place among all the elementary bodies. Those substances which do not combine with each other are either destitute of both the opposite forces referred to, or these forces are inactive in one of them, owing to the circumstances in which it may be placed. On the other hand, combination takes place everywhere if the forces (K) and (O) be different from each other in a determinate degree. If, for instance, there be a substance containing 20(K), and if it come in contact with another containing 1(O), the result will be a combination, and this new product will be able to act with a force represented by 19(K).

We have no reason to assume the existence of other chemical forces than those which we have called (K) and (O). All the elementary bodies seem to possess them, though uniformly in different degrees. It results from the doctrine of chemical proportions *(stochiometry)* that the quantities of the several elements which combine with each other vary according to certain definite proportions, if the forces are excited in different degrees by different circumstances. Nitrogen (N) combines with one, two, three, four, or five of oxygen (O, O^2, O^3, O^4, O^5,) and so with regard to the other elements. We have thus solid grounds for assuming the existence of certain values of the chemical forces; the relative proportions of which values may be expressed by whole numbers.

Another result of experience is, that these forces are exhibited in ordinary circumstances by all the elementary bodies, but that the conditions require to be modified, either to excite these forces, or to fix them in the substances in determinate quantities. We see oxygen attracted by potassium at the ordinary temperature, and hence conclude that such a force is always possessed by potassium. We cannot, however, produce any proof of this, for it is possible that the common temperature causes the production of that force in potassium, seeing that it ceases to attract oxygen at a temperature of

—150° Fahr. It is possible that the ordinary temperature has the same effect on potassium, as a red heat has upon iron.

Among the circumstances by which these forces may be excited or fixed in determinate quantities in the elements, may be reckoned a high temperature, the influence of light, the action of electricity, and especially the presence of another chemical substance. We shall here adduce a single example of each, and treat hereafter of this subject more fully in its proper place.

Heat excites the forces (K) as well as (O) in many substances; (K), for instance, in the metals, which are oxidized at an elevated temperature; (O) in chlorine, which combines with hydrogen on the application of a taper, producing hydrochloric acid.

Light causes the sudden combination of hydrogen and chlorine (H and Cl), and thus excites (K) and (O) in these two gases respectively.

Hydrogen and oxygen (H and O) are at once combined by means of an electrical spark, which thus excites in them (K) and (O).

(K) and (O) are excited by other substances, as, for instance, in the combination of hydrogen and oxygen (H and O), which is effected suddenly by spongy platinum, and more slowly by platinum foil.

The peculiar forces of two substances are not lost by their mutual combination; they only become quiescent, as it were, so far as each is counterbalanced by an equal quantity of the opposite force. Alum may be decomposed into sulphate of alumina and sulphate of potash; each of which has its proper character of (K) and (O), and that in the same degree as before their combination. Finally, potash and sulphuric acid (KaO and SO^3) may be decomposed in the same manner into Ka, O, S, and O^3, each of which has the same quantity of (K) and (O) as at first.

This is proved by every chemical analysis, effected by the action of other substances upon those which are to be decomposed. The forces (K) and (O), therefore, become only quiescent, and are not lost while the combination of the substances is in progress.

We are by no means able to enter into this idea, if we assume that the molecules of the united substances are quite close to each other. In this case a reciprocal annihilation of two opposite forces must occur. If we suppose that the molecules are very near, though not in contact with each other, we can easily conceive that the forces which proceed from the molecules, having a certain tendency towards each other, may seem to our senses to lose that portion of their strength which is expended in producing the combination, and yet may appear again in their original quantity as soon as the combination is dissolved.

Substances *persist*, therefore, in their combinations, by the same law in obedience to which they *become* chemically united; they are *decomposed* again by the same law if more powerful forces than those, which bring them together, act upon their component parts. They *become* combined, because two opposite forces, which either are present in the elements, or are excited by circumstances to a determinate degree, act upon each other, and so accompany the substances with which they are connected. They *persist* in their combination because these forces are not annihilated, though part of each is brought into equilibrium with part of the other. This part is thus prevented from acting externally. They may be *decomposed*, if more powerful forces act upon one of them, and if the decomposing forces be of the same species. Copper, for instance, separates silver from its solution in nitric acid; thus withdrawing the oxygen from the silver, and itself combining with the oxygen. Suppose copper to contain 1(K), silver 1(K), and the oxygen of the oxide of silver 3(O); a separation of the silver, which has but 1(K), must necessarily take place, because 3(O) may be neutralised by 3(K).

We have, therefore, a direct proof that these chemical forces are only quiescent, inasmuch as chemical substances are decomposed by others, which exercise a more powerful influence upon one of the combined substances than on the other. Hence again we deduce the conclusion, that substances are kept in combination by the same forces, in virtue of which they enter into combination.

B. Chemical Action is Action at Un-measurable Distances. Polarity of the Molecules.

It is a peculiar feature of chemical combination, that it acts at distances too small to be measured. To effect the combination, it is therefore indispensable that the particles should come very near each other. This is the reason why substances, if put in mutual contact while still in a mass, have, for the most part, either no action at all, or only an imperfect action upon each other, and why they act upon each other even at the ordinary temperature, if they are reduced to a very fine powder. This may be seen in the case of sulphur and copper. These substances have no effect at all on each other when in mass; but when reduced to powder they are combined by simple trituration, a great deal of heat being evolved in the process. We should err, however, if we supposed that minute division was the only cause of combination; trituration is, in the case supposed, only a powerful assistance. We see, however, when bodies are dissolved in water, that this state of division is a principal condition of combination. If anhydrous sulphate of soda and chloride of barium are triturated together, no change will take place at all; but if they are brought together in a dissolved state, that is, in a state of the minutest division, a perfect decomposition will result.

The effect of temperature, in such cases, is not simply to promote the combination of substances. Temperature facilitates combination, in the same way as solution in water does, where either one or both of the acting substances can be fused. No doubt the oxidation of metals in oxygen is promoted by an elevated temperature, owing either to the excitation of peculiar forces in the metal and the oxygen, or to the increase of these forces to a limited extent: but fused lead or volatilising zinc, for instance, has the particles very much divided and very moveable, under the influence of an elevated temperature. These particles, for this reason, are enabled to turn to the oxygen that very side which is necessary for the combination. We must therefore add this greater mobility also to the influence of the temperature, (as we remarked of solutions of salts.)

wholly independent of the elevated temperature itself. So with pulverised lead, we find that if shaken in air and water, it is soon changed into hydrate of oxide of lead; though a lump of lead, under the same conditions, is but slowly acted upon. Two gases, if mixed with a third of a neutral character, combine but slowly; the result of their action, however, is a perfect mutual attraction; as, for instance, when ammonia, carbonic acid, and atmospheric air are mixed. Thus the combination of gases is promoted by the mobility of the particles.

As it is necessary to the production of a chemical combination that the particles should be moveable, we infer that the different sides of the molecules have a different power of combining with a molecule supplied with an opposite force. The particles must be able to move, and it seems, therefore, that there are determinate sides in every molecule which prefer being united with molecules of an opposite force. In many combinations, when observed with the microscope, we perceive a vehement rotation of the particles, before they combine with each other.* This fact directly demonstrates a certain property of polarisation, an action of the force of affinity in a determinate direction, influencing an opposite force which also operates in a determinate direction.

That this must necessarily be the case, will appear if we examine somewhat more deeply the nature of the union between two elements. Potassium and oxygen unite by means of a force, which is not altogether annihilated after the combination, but of which a part still remains active externally; the other part is rendered quiescent by the mutual counterbalancing of two opposite forces. A particle of potassium, if it be an indivisible one, must be placed in *juxtaposition* with an indivisible particle of oxygen in this manner: [Ka | O] Their *inter-penetration* is impossible, because matter does not admit of penetration. One substance can by no means be closely wrapped round the other, in the form either of a ring or of a sphere, for in that case the enclosing sphere could not be regarded as an indivisible particle. It is impossible that the one should be distributed in particles round

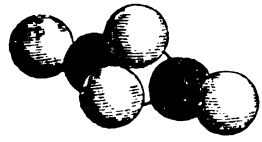
* See Harting in Bulletin de Neérlande. 1840. P. 257.

the other, for it is *one* molecule. The only theory, then, which remains for adoption, is that of an arrangement of the opposite particles *beside* and *near* to each other. If we suppose that each particle of potassium and oxygen is wholly and everywhere supplied in the same degree, with the forces (K) and (O), the effect of these forces will be to produce an approximation of the molecules, because the forces are opposite to each other, and the strongest attraction will take place at the point of approximation; in other words, the attracting forces may be supposed to act in the axis of two spheres.

Such a composite molecule can be united with molecules of the same kind, only by means of the general principle of attraction. Potash in mass is bound together not chemically, but physically, that is, by the universal force of attraction or cohesion. For the mass may be divided into smaller parts without disturbing the chemical equilibrium.

If polarity really exists in the simple molecules, so must it in the composite molecules. We can easily imagine this, if the substances, composed of one atom of each element, produce a binary combination, as in the case of potash; but it is difficult to form a conception of the nature of the combination, when two, three, or more molecules of one element are combined with one or two molecules of another. How, for instance, can we form an idea of the polarity of sulphuric acid (SO^3) and of phosphoric acid (P^2O^5)?

Fig. 1.



It is probable that the molecules of oxygen, being here the more numerous, are arranged *round* the molecules of sulphur and phosphorus (S and P), and that the force (K) of the latter element is neutralised by a part of the (O) of the former. But we cannot conceive how by any probable means (K) can be distributed in S and P, or what may remain of (O), capable of acting and manifesting itself externally.

In every case, we may deem it probable that the simple and the compound molecules are combined together in determinate directions, and that their character is fixed by the form which the compound molecules assume. We see, then, a determinate relation between the arrangement of molecules and isomorphism, between the number of atoms and the form of the crystals. For if the atoms of sulphuric acid and selenic acid are arranged in the same manner, we can conceive that when these acids combine with the same base to form salts, the same form of crystals may be produced, although we cannot, *à priori*, determine from that arrangement of the molecules what the form of the crystals may be.

The difficulty we have noticed, as to the combination of several molecules into one whole, is greatly increased, if we endeavour to form an idea of that state of polarisation which exists in every compound organic molecule. We cannot explain how the atoms of sugar are combined together; and so with every other organic compound. It is, however, certain that here also polarisation exists; because in crystallized sugar ($C^{12}H^{11}O^{11}$), two equivalents of water are contained, for which two equivalents of oxide of lead (PbO) may be substituted. Hence it is evident, that a constant proportion exists between the 2 of oxygen in 2HO and 2PbO, and the 9 of oxygen in $C^{12}H^{9}O^{9}$.

It thus appears that the oxygen of the sugar, after combining with carbon and hydrogen, and after having several times neutralised their forces (K), has forces (O) still remaining to oppose to water or to oxide of lead, these in their turn possessing (K), by which they are enabled to combine with the sugar. The other elements of the sugar leave to the 9 atoms of oxygen, after subtraction of the quantity applied to the neutralisation of the carbon and hydrogen, as much force as enables it to combine with the same quantity of oxide of lead as can be attracted by two of sulphuric acid ($2SO^3$), thus:—

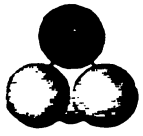
$C^{12}H^{5}O^{9}$, require 2PbO.
$2SO^3$, ... 2PbO.

If, then, we assume a state of polarisation in the elements of sulphuric acid and oxide of lead, and if we imagine, that resul-

tants of all the forces which reside respectively in oxygen and lead, and in oxygen and sulphur, are developed—resultants which influence each other, though co-operating as a whole—we cannot form any other idea, than that a similar resultant proceeds from the elements of sugar, directly the opposite of that which proceeds from the atoms of the oxide of lead. We cannot, however, determine, with any probability, how this resultant may be obtained.

There is, however, a class of organic substances, in which this division into groups is obvious, namely, those substances of which we know the radicals, acetyl, formyl, ethyl, methyl, &c. We attempt in vain to form an idea of the various substances, of which the radicals are still unknown; as, for instance, sugar. If a simple substance can combine, with but one atom of another, such a substance is probably unipolar, if with two, bipolar, &c. And so with more compound substances. It is therefore likely that the molecules of bi, tri, quadri, quinti-basic acids are just as much polaric; and that in a tribasic acid, for instance, the three atoms of base are arranged *round* the acid in the form either of 3 of oxide or of water (3RO or 3HO), or 2 of oxide and one of water (2RO + HO), or one of oxide and 2 of water (RO + 2HO).

Fig. 2.



C. The Influence of Circumstances upon Chemical Forces.

We may employ the quantities of different substances, which can combine with the same element, to express the measures of the chemical forces, which reside in them. Whether one substance can separate another from its combinations, may be ascertained by experiment. Now, experiment informs us that in the same circumstances different bodies possess different quantities of chemical force. For instance, sulphuretted hydrogen is decomposed by iodine, and sulphur separated; hydriodic acid by bromine; hydrobromic acid by chlorine. These simple substances, therefore, stand to each other in this order of affinity, chlorine, bromine, iodine, sulphur. So with the metals, silver, mercury, copper, lead, and zinc.

Each is precipitated from its solution by that which follows it in this order of succession. There is thus more force of affinity in each of the subsequent, than in each of the preceding metals. In alkalies the affinity for sulphuric acid diminishes in this order—baryta, strontia, potash, soda, lime, magnesia, ammonia.

The chemical forces, however, emanating from bodies, are modified by so many particular circumstances, that it is as yet impossible to lay down determinate principles.

1° If, for instance, any substance is volatile, it is easily liberated from its combinations. Carbonic acid, therefore, passes off very quickly; and even hydrochloric acid, though much more powerful, does so, because it is volatile. Phosphoric acid expels even sulphuric acid, because it is unaffected by fire. Silicic acid, though possessed of but little power, expels many other acids when heat is applied, because it is not volatile.

2° If any substance has a tendency to produce an insoluble combination, then its force of affinity is considerably increased. Of this we have a striking example, in carbonate and acetate of potash. If carbonate of potash is dissolved in water, the carbonic acid is expelled by acetic acid; but acetate of potash, if dissolved in alcohol, is decomposed by a stream of carbonic acid, because carbonate of potash is insoluble in alcohol. If a double decomposition take place, the bases and acids are always arranged and combined together in that order, in which the least soluble salts are produced.

3° It is a remarkable peculiarity in the modification of affinity by the influence of circumstances, that many combinations are much more easily effected, if some other substances must first be separated, than if the substances are brought into mutual contact in an uncombined state. Lime, if quite dry, does not absorb carbonic acid, though hydrate of lime does so very easily. Oxide of ethyl does not combine directly with acids; but it does combine if the acid be made first to separate water (HO) from alcohol, and thus to form the ethyl with which it is to combine. If a metal is dissolved in hydrochloric acid, the metal (M) is substituted for the hydrogen (H) of the acid,

for MCl+H is produced by M+ClH. In this case Cl and M are easily combined, because M is substituted for H, though it is often very difficult to unite M directly to Cl. It is probable, that the double decomposition is very much promoted by the double substitution which then takes place (Graham). In Graham's opinion, the power which the hydrates of silica and alumina have of forming combinations, ought also to be ascribed to substitution, since the same substances, after being subjected to a red heat, scarcely combine with other bodies at all.

4° Mutual decomposition of two salts takes place, not only when one or both of them become insoluble, but also when one of the two new products, or both, are less soluble than those which were originally employed. Such is the case when solutions of sulphate of soda and nitrate of potash are mixed together. If sulphate of copper be mixed with chloride of sodium, the blue colour is changed into green, which proves the formation of chloride of copper. It is possible, however, that this may result from mere affinity, because sulphate of copper can be decomposed by hydro-chloric acid, and chloride of sodium by sulphuric acid.

5° Pressure is another circumstance, which influences chemical forces. If it be very great, no hydrogen is disengaged from diluted sulphuric acid and zinc. If the vessel be closed, the evolution of gas is diminished and finally stopped; but it begins again, whenever the vessel is opened.

6° If carbonate of lime is heated in a close vessel, none of the carbonic acid is disengaged; but it is otherwise when carbonate of lime is heated in the air, at least in the uppermost layers of heated air. But if atmospheric air or steam be conveyed through a tube, which contains carbonate of lime, then all the carbonic acid passes off. If hydrogen pass over red-hot oxide of iron, water and iron are produced; and if steam pass over red-hot iron, hydrogen and oxide of iron result. In this case the affinity is modified by the atmospheric air, which surrounds the substance; and this phenomenon is thus related to the diffusion of gases.

It appears, then, that a considerable part of what we see

as to the inclination of substances to combine or to separate is to be ascribed to the influence of circumstances. To effect a combination, it is necessary that the chemical forces, included in the substance, should be either excited or elevated to a determinate degree. It is only thus that we can conceive, how a molecule can acquire the power to combine with 1, 2, 3, 4, &c., molecules of another substance, so as to produce well-defined chemical compounds. The quantities of chemical forces are thus graduated, as it were, and substances are combined in proportions, which depend on the quantity of those forces; such combinations, however, do not occur until two opposite forces are excited to a certain degree by the influence of determinate circumstances. If, for instance, iron be slightly heated in the air, the protoxide (FeO) is produced; if it be heated to a greater degree, the peroxide (Fe^2O^3). Why do the same iron and oxygen combine together in two different proportions by means of the same agent, heat?

If we suppose, that at the ordinary temperature iron has a tendency to combine with oxygen, and *vice versa*, but that there exists no proportion at all between the quantities of the forces, (K) and (O), which reside in them respectively, then the iron would not enter into combination. This is what we observe in dry air. If the iron be heated, its force (K) is excited, and so is the force (O) in the oxygen, when in contact with the heated iron. A combination of the opposite forces, and consequently a combination of the iron and the oxygen (Fe and O), occurs only in the case where both forces increase to such a degree, that they both reach an equally high maximum, with reference to the circumstances in which they exist. A dull red heat makes these forces increase to a limited maximum only. If we heat FeO and O to a still greater degree, these forces get a new increase, and Fe^2O^3 is formed only when the forces of Fe and O have attained a new maximum.

As to the production of some other compounds, we must adopt a different principle. If, for instance, sulphur is to be oxidized into SO^2 and SO^3,—sulphurous and sulphuric acid

—then the sulphur must in each case be placed in peculiar circumstances. When sulphur is burned in the air, the elevated temperature affects S with (K), and oxygen with (O); in other words, the forces resident in sulphur and oxygen, must be excited in such a manner that S is combined with O^2. The oxidation into sulphuric acid (SO^3) is effected in a different way. Sulphurous acid (SO^2) is brought into contact with a substance possessing energy, and which is known to have the power of exciting action in other substances, and even of itself giving off 1 equiv. of oxygen, namely, with hyponitrous acid (NO^3). SO^2 is thus predisposed to take up O again; NO^3 excites new forces in SO^2, and the combination of O with SO^2 is effected in the same manner, as that of gold with chlorine, by the contact of the gold with chloro-nitrous acid (aqua regia). This result is attained because 1 equiv. of oxygen very easily escapes from the hyponitrous acid (NO^3), which it contains, and this oxygen, being in the *nascent state*, retains that force by which it was previously kept in combination with NO^2. As regards the gold, it is NO^3 also which excites the force in this metal, producing its combination with Cl, or with a substance which possesses the (O) force.

Phosphorus may be combined with O^3 at the ordinary temperature, and the product is phosphorous acid. To form PO^5, phosphoric acid, however, a more elevated temperature than that necessary for combustion is required.

The predisposition either of simple or of compound substances to form new combinations, the excitation of the forces resident in them, and which were neutralised so as to be wholly or partly imperceptible externally, is produced sometimes by one, sometimes by another circumstance, often by the influence either of a different substance or of a certain temperature, or of light, or of electricity. We learn from experiment that the excitation of forces takes place so, that determinate and constant combinations are produced. It is, therefore, necessary that the measure of the opposite forces, which are excited, should be a constant one also; at least a maximum of both the opposite forces must be produced, before any combination can result, though the forces may in-

crease with the increasing influence of circumstances. This maximum may be superseded again by other circumstances, producing a new combination of the elements.

D. Catalysis: Molecules in Motion.

Berzelius has directed our attention to a power, which some substances possess, of exciting chemical action by their presence, though they themselves are exempt from the effects of such action. This power he calls Catalysis.* It is distinguished from ordinary chemical force, in so far as the latter, while it is exerted by one substance upon another, yet generally reacts upon both. If sulphuric acid acts upon soda, an action is effected by both, which reacts upon both. If oxygen come in contact with phosphorus, at an elevated temperature, then they are mutually combined. Though the action might have proceeded from the oxygen to the phosphorus, the oxygen nevertheless is drawn within the circle of action.

The effect of catalysing substances is entirely different. Spongy platinum condenses hydrogen; and so soon as oxygen comes in contact with it, water is produced, while the spongy platinum undergoes no change. Hundreds of pounds of hydrogen and oxygen may be combined together by means of a small piece of spongy platinum. Thus the platinum produces a force, which influences at once the hydrogen and the oxygen, and causes an action, from which the platinum itself is exempted. Such is the force which Berzelius calls *catalysis.*

The greater part of the substances, which excite chemical action in other bodies, and are themselves involved in the reaction, are undoubtedly affected by this catalysis. Possibly catalysis may always be present among chemical causes, so that, if SO^3 and NaO—sulphuric acid and soda—for instance, are combined together, a force proceeds both from SO^3 and from NaO, each of which is similar to that proceeding from platinum, when in contact with certain gases. Catalysis might be defined as the *exciting* cause of chemical action, and this excitation may take place whether the exciting substance be contained in the circle of action or not. We reckon, how-

* Jahrbuch für 1836, von Schumacher, p. 88.

ever, as pure catalytic phenomena, only those in which the substances provoking the combination do not enter into that circle. Those bodies thus possess the power of exciting, but have not the property of sharing in the combination which is the result of their action.

This force is possessed, not only by spongy platinum, but by platinum in substance; for if a piece of platinum foil be placed in a mixture of hydrogen and oxygen, the gases, as they pass along its surface, form small quantities of water, so that in a few hours all the gas has disappeared, and water has taken its place.

Nor is platinum the only metal which has this property. Every substance which is porous, is possessed of it in a greater or less degree. Thenard and Dulong have detailed a great many experiments on the subject, and have demonstrated, that this property belongs even to glass when pulverised, but only at a somewhat elevated temperature — namely, at 572° F., and to gold and silver at a lower temperature. It had previously been discovered by Sir Humphry Davy, that platinum, if placed in the vapour either of alcohol or of ether, began to glow, and caused a combination between the vapour and the oxygen of the air. Spongy platinum was afterwards discovered by Edmund Davy, who observed that it possessed this property in so high a degree, that if the platinum was moistened with alcohol, acetic acid was produced from the alcohol while the platinum was glowing. Before the discovery of Thenard and Dulong, it had been remarked by Döbereiner that hydrogen and oxygen could be combined together by means of spongy platinum. This discovery was extended by the two former to several other substances.

The effect of deutoxide of hydrogen, (HO^2), when in contact with various substances, has been classed by Berzelius with the same series of phenomena. It explodes, if brought in contact with platinum, silver, peroxide of manganese, and even with organic substances, such as fibrin. Oxygen is disengaged, and water (HO) remains*. In every case, where

* It is now known that at the same time part of the oxygen is combined with the fibrin, and oxyprotein produced. (Scheikundige Onderzoekingen, Vol. I. 1

the solid substance can combine with the whole quantity of oxygen, there is of course only an ordinary chemical action; but if this combination does not take place, and if the action occurs on contact simply, the phenomenon is that which Berzelius calls catalysis.

This term ought further to be used with reference to the change of alcohol into ether, by means of acids. Hydrate of sulphuric acid—the common oil of vitriol of the shops—into which alcohol is dropped at an elevated temperature, is not diluted by the water produced, but a mixture of oxide of ethyl and water distills off. Sulphuric acid, therefore, catalyses at that temperature the elements of alcohol into oxide of ethyl and water, without itself combining with either. The same effect is produced by other acids, especially if they are powerful. To the same class we refer the changes, produced on starch by sulphuric acid, transforming it either into dextrine or into sugar—the changes which are produced by acids on starch, gum, sugar, forming humic acid, ulmic acid, and formic acid—and also the action of emulsine upon amygdaline. Several other phenomena, besides, are referred by Berzelius to the same class—phenomena ascribed to organic chemistry—as for instance, the transformation of starch into gum and sugar by diastase, the transformation of sugar into carbonic acid and alcohol by yeast, and also the changes which take place in the bodies of animals and plants. Transformation by diastase ought doubtless to be classed with these phenomena. An exceedingly small quantity of this substance changes a large quantity of starch into gum and sugar; but it is also possible that the diastase itself is at the same time acted upon, and that thus we have, in this instance, no pure catalysis. This is the case especially with yeast, which, during fermentation, changes sugar into carbonic acid and alcohol, and probably it is much more so in the animal secretions.

Founding on these considerations, Liebig has been led to reject catalysis entirely,* and to give a totally different explanation of the facts. He has *assumed*, that chemical forces are in action in those substances, which, according to the supposi-

* Chimie Organique. Introduction.

tion of Berzelius, are sufficiently capable of exciting action, though without taking part in that action; and he thinks, that by such chemical action, another may be excited in other substances. He adopts the principle, indicated by Laplace and Berthollet, that a molecule, being put in motion, can communicate its motion to others, if in contact with them. He applies this principle to yeast especially. The opinion of Berzelius is, that sugar is changed into carbonic acid and alcohol by this substance, just in the same manner as alcohol is changed into ether and water by sulphuric acid; and as water is produced from hydrogen and oxygen by platinum. Liebig, however, assumes that yeast is continually in a state of decomposition; that it thus undergoes a change in its own elements, and that, if put in contact with sugar and water, it disturbs the chemical forces, by which the elements of sugar are combined together, and so produces alcohol and carbonic acid;—this disturbance being caused by the change in the elements of the yeast, which follows the disturbance of its chemical equilibrium.

Though it seems to be proved, that yeast is really changed during the alcoholic fermentation, and cannot therefore be said to act by catalysis, yet this series of chemical phenomena is not reducible to any class of ordinary phenomena, and we are consequently obliged to assume three different forms of chemical action.

1st. That which is effected by a substance, without any reaction, but which is transferred to other substances *(catalysis)*.

2d. That which is effected by certain substances and transferred to others; the primary substances being at the same time decomposed, though they do not communicate any of their elements to the new products *(fermentation)*.

3d. That which is effected by certain bodies, but which produces a complete reaction upon the bodies themselves, so that common products result from both the active or influencing substances, and those which are acted upon *(ordinary chemical action)*.

We have already treated sufficiently of the third cause of

action; we must dwell, however, more particularly on the first and second.

Catalysis. In our opinion it is not to be denied, that a particular action must proceed from spongy platinum, or from platinum in mass, when hydrogen and oxygen combine to form water—from sulphuric or any other acid, when oxide of ethyl is produced—in the transformation of starch into gum and sugar by sulphuric acid—in the change of sugar into humin by diluted acids. This action differs in character from ordinary chemical action. In the latter case the substance, from which the action proceeds, is always itself comprised within the circle of effects, and generally enters into new combinations. There are, however, a great many similar actions, which are erroneously referred to ordinary chemical action. If, for instance, gold or platinum be dissolved in aqua-regia, hyponitrous acid (NO^3) takes no part in the combination. Either NO^3 or some other powerfully acting substance, however, is indispensably necessary to produce the combination of chlorine with gold or platinum. A still more striking example is afforded in what has already been mentioned, namely, that the presence of a third substance is often required for the production of a combination, though it be separated after the combination has taken place—as in lime, water, and carbonic acid (see above, p. 24). The water, in this case, is required for effecting the union between carbonic acid and lime, and will, notwithstanding, soon be separated. It does not enter into the combination which results.

Whatsoever name we may give to this acting cause, it cannot be denied, that there are a great many substances which predispose others to combination, enabling the latter thus to enter into combinations, which without their agency could not take place. The action which Berzelius has distinguished by the name of catalysis, is thus a peculiar mode of exciting a chemical action.

What conception ought we to form of this catalysing action?

Some molecular forces are hidden in the elements. One of these forces we know to possess the great power of producing

combinations between dissimilar substances. Such forces generally proceed from the very substances on which they react. Catalysis is precisely the same force, without the reaction, however, on the substances whence it proceeds.

If we transmit a small electric spark through a mixture of hydrogen and oxygen, in a gaseous state, the whole is immediately combined. Two molecules—one of each—first combine, and from these the action is communicated to the whole. They have been called by Laplace and Berthollet, *molecules in motion*. We perceive, however, in this example an action proceeding from two molecules of hydrogen and oxygen, and transferring itself to thousands of molecules of the same elements; but the particles originally affected by the electrical spark are not involved in the subsequent action.

Something of a similar kind we observe in catalysis. Spongy platinum does not enter into the combination of hydrogen and oxygen. We see, however, this difference between the case in which combination is effected by means of platinum, and that in which it is effected by an electrical spark—the particles of platinum are in the state of moving molecules, no influence apparently being exercised by external causes.

It would be an interesting experiment, to expose spongy platinum to a mixture of hydrogen and oxygen, reduced to a very low temperature, with the view of ascertaining whether platinum would then possess the same power. It is probable that the metal would not retain this property at every temperature. Nay, it is certain that pulverised glass produces the combination of these elements, but not at a lower temperature than 572° F.—thus acquiring at 572° F., the same power which platinum possesses at the ordinary temperatures. A neutral substance may therefore be made equal to platinum, by an elevation of temperature. It is further known, that a determinate temperature is required to convert alcohol into oxide of ethyl and water, by means of sulphuric acid; that humin is formed from sugar by means of an acid, but not at every temperature; that the power which sulphuric acid possesses, of converting starch into gum and sugar, is not unlimited, but that a determinate temperature is required for that purpose.

If, in this manner, we go over the series of catalytic phenomena, we observe that the influence of temperature is almost always indispensable.

Now, it is known, from abundant experience, that heat has the power, greatly to modify the chemical forces resident in substances. This is very clearly shown by the innumerable products, obtained by dry distillation at different temperatures. If, then, the influence of heat on the substances, said to be catalysed, be communicated to them by the catalysing substance,—if it be the heat, for instance, which causes oxide of ethyl and water to be produced from alcohol, but if that heat must be communicated to the elements of alcohol by means of an acid,—should the heat, in this case, prefer such a medium,—the idea of catalysis contains nothing repugnant to acknowledged principles.

However this may be, it cannot be denied, that there are many cases in which chemical action proceeds from a substance, which is not itself comprehended within the circle of such action. Although this be a deviation from ordinary chemical action, the idea seems not to be opposed to any sound principle, and creates no greater difficulty than occurs in the case, where all the substances, which excite any action, enter into the combination.

The peculiar property of spongy platinum has been called, by some philosophers, *surface action*. To this action they have ascribed every phenomenon, similar to that produced by the peculiar influence of spongy platinum. I must confess, that I understand the meaning of surface action as little, as I do that of contact action. A surface cannot produce an action; that must necessarily be effected by matter—by the forces imparted to matter, which manifest themselves under certain circumstances, especially when the matter is minutely divided,—though, under other conditions, the same forces are quiescent. We should, I think, approach nearer the truth, by inverting our conception of the subject, and assuming, not that substances obtain a new power by minute division, but, on the contrary, that by their accumulation into masses they become powerless,—that the forces present in the molecules

are prevented from acting, being reduced to a state of quiescence. When iron is in mass, it shows but a slight tendency to oxidation: but when minutely divided, it cannot possibly be brought even in contact with atmospheric air, at a low temperature, without becoming red-hot, and at the same time becoming converted into an oxide. Cobalt, nickel, and uranium possess the same property (Magnus). It is true, that in these spongy bodies, obtained by reducing their oxides by means of hydrogen at the lowest possible temperature, the oxygen from the atmosphere is apt quickly to condense; but is this condensation an effect, produced by the iron in the metallic state, or by something else—by a power dwelling in the matter, *i. e.* the iron, or by a power which is without? If it be absurd to suppose, that this power is present in anything but the iron, then the power coincides with chemical attraction. It verifies the proverb, *corpora non agunt nisi soluta*, but in a more definite form, *corpora non agunt nisi dirisa*. Chemical action operates by molecules, not by masses. In the masses the chemical forces are rendered powerless and quiescent. If we could isolate the molecules of all the elements, these forces would show their potency in the molecules.

I see no reason why, with regard to spongy platinum, that is platinum so minutely divided as to approach the molecular state, I should assume that anything else takes place, than with regard to iron, cobalt, nickel, and uranium in the same spongy state. On the contrary, spongy platinum wants something, which the others possess. Their molecules condense gases around themselves, and if the gas be oxygen, this condensation is almost contemporaneous with the oxidation of the metal. Thus one molecular action is succeeded by another, and so determinate quantities of the two substances become and remain united. This power is not exercised by platinum, and thus it possesses one power less than iron. This manifestation of molecular forces, without the intervention of external circumstances, may be observed in every element, provided it can be minutely enough divided. There is a whole class of metals which, if pulverized, burn away in chlorine

at the common temperature. The power of exciting a red heat, and of combining chemically, exist both in the chlorine and in the metal; they only need to be placed in proximity, and forthwith this power is exhibited. If tartrate of lead be heated to a proper degree, it yields lead, in a state of very minute division ($C^4H^2O^5 + PbO = C^4O^4 + H^2O^2 + Pb$.) Lead in this state is an exceedingly good pyrophoric substance; when it comes in contact with the atmosphere, it is instantaneously oxidized, even though previously saturated, either with carbonic acid or with nitrogen.

From the whole series of pyrophoric substances, we learn still more clearly, that all the elements manifest their properties energetically, if, when in a state of minute division, they are only brought into contact. Phosphorus and liquid bromine cannot be brought into contact, without entering vehemently into combination.. If a solution of phosphorus in bi-sulphuret of carbon, be poured upon paper, and exposed to the air, the sulphuret evaporates, and the phosphorus remains in a state of minute division. Whenever this operation is completed, the phosphorus absorbs oxygen from the atmosphere, evolves heat, produces phosphoric acid (PO^5), and the paper burns.

In all these phenomena, nothing is visible but molecular action, which, however, has been called chemical. This action cannot proceed from masses, because the molecules, placed in close juxta-position, counterbalance each other. Chemical bodies, therefore, in a chemical point of view, are entirely different from what they appear to be when in mass.

There is another substance also, which deserves particular notice, to wit: finely powdered charcoal. Its well known power of condensing gases and retaining metallic salts, colouring matter, &c., is ascribed to a surface action. There are, however, in regard to this substance, so many cases in which we perceive a real chemical action, that we can have no doubt of the proper cause. Thus we find that when a mass of charcoal, recently made red-hot, and allowed to cool *in vacuo*, is exposed to the air, it takes fire; so when sulphuretted hydrogen and oxygen are absorbed together by charcoal,

water is produced, and sulphur separated; and when a solution of acetate of lead is filtered through charcoal, metallic lead, combined with the charcoal, remains behind.

We may therefore assume, that these well known properties of charcoal correspond with the chemical tendencies of the molecules of carbon in the porous charcoal, the molecules not being rendered inefficient by aggregation.

Platinum possesses chemical tendency in a high degree, but it is of such a kind, that it does not react upon the platinum. When in mass, the metal is no more devoid of that tendency than the iron in a similar state is, of the power of attracting and combining with oxygen.

Hence, it may be inferred, that we have good reason for distinguishing, by a peculiar name, such actions, as proceed from certain substances without reacting upon themselves; and we have to acknowledge that to the introduction, by Berzelius, of the peculiar term *catalysis*, we are indebted for a more correct idea of the nature of ordinary chemical action.

What is called the *nascent state* of substances, is that condition of the elements, in which they exhibit both analytic and catalytic phenomena; in which, being free and unconstrained, not rendered powerless, either by being agglomerated into masses, or by combination into compounds, they show themselves in their proper chemical condition—that is, an active one, in which they can operate upon others, excite a slumbering energy, and cause combinations and decompositions, in which they themselves may either participate or not.

This *nascent* is the real *chemical state* of bodies. In that state both the elements and the compounds exhibit themselves in their true character. In the organic kingdom the greater number of substances are actually in that condition; and to this *nascent state* we ought to ascribe the numerous peculiar phenomena, apparent in organic substances.

It seems to me, that we ought to take what has been called by Liebig *motion of molecules*, in a sense corresponding with the view now stated. Activity, in a chemical sense, indeed, cannot be excited by mere motion; but one chemical energy

is awakened by another; the chemical equilibrium is disturbed, the influence of cohesion is broken, and the elements are brought back to their free and proper chemical and molecular condition.

Disturbance of chemical equilibrium. It is a property of the chemical forces, which are active in any substances, to excite analogous forces in others. We notice this especially in organic nature, and it is nowhere more strikingly illustrated, than in the nutrition of animals. Blood, a homogeneous fluid, circulates through very different parts of the body. In the muscles it sustains muscles, in the liver it supplies the component parts of the liver, and from it the gall is there secreted; in the kidneys it maintains their various parts, and secretes the urine, &c. None of these secretions appear in the blood with their peculiar qualities; of some of them not even a trace is found in it. But the four organic elements of the whole are to be found in protein and its combinations, in the colouring matter of the blood, &c. The elements of protein might, no doubt, be transposed in the liver, &c., by means of catalysis, and so the component parts of the liver and gall be produced from it. It would only be necessary, then, that the constituent parts of the liver should be put in contact with the component parts of the blood, and the forces of affinity, resident in the substance of the liver, &c., would not require to influence those in the protein, or to produce any chemical alteration in its component parts.

Other causes, however, ought undoubtedly to be considered. For instance, a change of its component parts takes place in the liver itself, and, from the first, chemical forces actively operate therein. For the continual change of its component parts is a chief characteristic of every living organic substance. These forces may disturb the chemical equilibrium of other substances, and cause the formation of new products. If the constituents of the blood—the combinations of protein, the colouring matter, &c.—enter the liver when it is in a state of action, and are there put in contact with the gall during its secretion, and with the substance of the liver itself, which is in a state of continual alteration, then the result will be, that

this change of their component parts having taken place, the action will be transferred to the elements of the blood, and will maintain the secretion. If, on the other hand, the constituents of the blood are in a state of continual change, then the circle of action in which they are involved will extend to the mass of the liver; and so with every organ.

We have, however, no more knowledge of the manner in which this secretion originally commences—whether it proceeds from the blood or from the secreting organ, or whether each of these contributes its part—than with the manner in which the first germ of the whole organ, the liver, is produced, or in which the germ of the animal is converted into an animal. But the continuance of the action—the duration of secretion—entirely corresponds with some other phenomena, which we may observe separately, and which therefore throw light upon these animal actions. This is the case especially with fermentation, from which Liebig has drawn many illustrations, for the purpose of clearly exhibiting his ideas; and with the same view we shall also avail ourselves of the same process.

Yeast changes sugar into carbonic acid and alcohol, and is at the same time changed itself. The latter change causes the former, and is only transferred to the sugar. If we substitute blood for yeast, and the liver for sugar, we may form an idea, more or less, of the secretion of the gall. The component parts of the blood are continually undergoing change. This constant change of the component parts in organic bodies is a chief cause of the continuation of their existence. The liver without intermission assumes new parts and loses others. This process we call nutrition. At the same time that the parts of the blood in the substance of the liver are thus undergoing change, chemical forces are excited; these forces are transferred to the elements of the blood, and so are enabled to produce from them the gall. This takes place the more easily, as the blood itself is also in a state of continual alteration, and thus readily yields to the impulse which, in some way or other, is communicated to it. As the impulse varies, so does the effect. Hence that great diversity in the

secretion of very dissimilar substances, which are in a state of alteration, from the same fluid—that is, the blood, which is itself at the same time in a state of decomposition.

From the nutrition of the cellular texture, however, which must be produced from the component parts of blood, and from the nutrition of all the secreting organs—which, besides producing the secretion, maintain themselves by separating what they require from the constituents of blood—we learn that catalysis cannot be left out of consideration in the mere process of nutrition. Further, we must apply the same principle to all the solid parts of the body, which are compounds of protein. The muscles, for instance, have the property of secreting protein from blood, and converting it into fibrin; on the other hand, when protein is deficient in the blood, this fibrin is taken from the muscles and converted into blood-protein, as in diseases of long continuance and in emaciation. Muscles have thus the property of forming muscle-fibrin by simple contact, if protein abounds in the blood, and this result can be ascribed only to a cause similar to that, by which crystals gradually accumulate from solutions of salts. It is at least a peculiar action, different from ordinary chemical action, which takes place when the plasma of blood is transformed into muscles, which in composition do not essentially differ from the plasma. The same is the case with the production of hair, nails, and permanent horns.

Let us now proceed to inquire into the influence, by which chemical forces in action excite new forces in other substances generally.

In the inorganic part of chemistry, we perceive some phenomena, which demand particular notice. For instance, platinum is not dissolved by nitric acid, but if previously alloyed with silver, it is dissolved by that acid, as well as the silver. The oxidation of the silver thus becomes transferred to the platinum, which, by itself, could not be brought into that condition (Liebig). If deutoxide of hydrogen be put in contact either with oxide of silver, or with peroxide of lead, oxygen is lost, not only by the deutoxide of hydrogen, but also by the metallic oxides. The disturbance of the chemical equi-

librium in the one compound transfers itself to the other; the motion in which the molecules of the one substance are involved, is communicated to the molecules of the other.

Some chemical compounds have a very slight internal cohesion. Their elements are in a state of unstable equilibrium; they are either decomposed by a slight external disturbance, or they enter into new compounds. To this series belong oxide of chlorine, iodide of nitrogen, the fulminates, &c. It is easy to conceive that such substances, when in contact with other substances, also in a state of action, must immediately disturb the chemical equilibrium of the latter. Deutoxide of hydrogen belongs also to this series of compounds. But the greater part of chemical substances do not disturb this combination—this state of neutrality or of equilibrium, among the forces in other substances—unless they themselves can combine with one or more of the elements of those substances. Sulphuric acid readily separates oxygen from peroxide of manganese; but it does so, only, because it can combine with the protoxide. Heat, light, electricity, &c., may put the molecules in motion, and cause the production of combinations, which are different in kind, according as these agents are more or less intense in their action; but, in organic substances, we perceive that a slight disturbance of chemical action in a part of the substance extends through the mass, or passes from the one to the other. If, for instance, a single spot of an organic substance is put into a state of putrefaction, the putrefaction forthwith spreads through the whole mass. If a piece of rotten wood be united with a sound piece, the latter will quickly become rotten also, &c. Thus the disturbed action of organic forces disturbs others in their turn. What we perceive in crystallisation and in the explosion of gunpowder, is connected with this principle. A fluid may long remain uncrystallised; but when one crystal is formed, a great many others often succeed. If a grain of gunpowder in the midst of a large quantity is inflamed, the action spreads through the whole mass. For the same reason we perceive in organic digestion the appearance of biline, as a principal substance from which a chemi-

cal action, effecting the assimilation, proceeds. It is very easily transformed and changed into bili-fellinic acid and cholic acid. This is very strikingly illustrated in every kind of fermentation.

Fermentation. A great many organic substances, if exposed in a fluid state to a determinate temperature, exhibit an internal motion, produce bubbles of gas, and at the same time are chemically changed. Such is the case with all kinds of sap from plants, especially those which contain sugar. This change is caused by organic substances entirely different from each other, but yet very composite. In proportion as an organic substance consists of a more complicated group of other compounds, formed of variously arranged elements, all combined into one whole,—the more easily are these elements transformed, the less powerful are the uniting forces, and the more readily are new combinations produced. Among such substances are to be reckoned albumen, fibrin, animal gelatine, vegetable albumen, gluten, and all the substances in which these are contained. When one of them is mixed with saccharine matter, the phenomena above mentioned soon manifest themselves, and what we call *fermentation* commences. According to Liebig, the sugar is changed into carbonic acid and alcohol, by the disturbance of the chemical forces, which previously kept the atoms of the sugar together. This disturbance is an effect of decomposition in one of the said complex substances; which decomposition is continuous, and, so long as it lasts, disturbs all the organic chemical forces around. If this opinion be correct, then either the albumen must always be in a state of decomposition, or the fermentation does not begin until these complex substances enter into decomposition themselves; and the decomposition of albumen must therefore depend upon something else. The former view is not confirmed by observation, because it is impossible that these complex substances should be produced and decomposed at the same time. They could not be formed *into* the organic substance, and exist at the same time in a state of decomposition. But it is also indicated by observation, that they may be kept for some time

out of the organic substance, which produces them, without the manifestation of any phenomena of decomposition. If, for instance, they be dried, they may be preserved for an indefinite time. It is not determined whence the decomposition in these complex substances proceeds. The forces which keep them united have a chemical character, and they cannot be disturbed by any other than chemical forces. Thus the enigma still remains without a solution. A cause still requires to be indicated, by which the first motion of the molecules in these complex substances is originated—as, for instance, when, after being dried or preserved for a long time, they are put into sugar and water, and produce a fermentation. According to Liebig, yeast is always in a state of decomposition, and this decomposition is transferred to other substances, comprehended in the circle of action, more especially sugar; but still the question remains, how does yeast enter into the state of decomposition? Why does the same change among its elements take place in yeast, as yeast communicates to sugar? Is there still another substance which causes the decomposition of yeast, in the same manner as yeast causes that of sugar? If we effect the change of sugar into carbonic acid and alcohol, by means of gelatine, which has for years been preserved unaltered and in a state of non-decomposition, then the question is, how does the decomposition of gelatine commence, whenever by its agency the formation of alcohol—that is, fermentation—is effected? By what cause is it brought into that state? Here we must pause, for we can give no sure explanation. We may, however, assume, with Liebig, that very complex bodies contain atoms, loosely combined, which are decomposed by external causes, as easily as the fulminates, &c.* A determinate temperature is, no doubt, to be reckoned among these external causes; a temperature which need not exceed the average temperature of the atmosphere, and so may be what we call a low temperature, but which, nevertheless, is as capable of changing complex combinations, as one more elevated is of

* Scherer has proved, that fibrin, if placed in oxygen, absorbs it, and produces carbonic acid. (Ann. der Chem. und Pharmacie. 1841.)

transforming all the organic bodies in a large series of pyrochemical products, whose characters entirely depend on the temperature. If we observe, that the elements of organic substances are brought into different chemical states by different temperatures, so as to unite into new combinations, we may ascribe a catalytic influence to heat. If this be applied in reference to those plants, the functions of which are suspended in winter, and which are revived by the warmth of spring, and if it be extended to all the substances, which are more or less dependent on the influence of temperature, then we should seem entitled to assume heat as the primary source of chemical change in the component parts of complex organic substances; a change which, once originated, may be transferred to other substances. To heat, then, we ascribe catalytic action; and thus the commencement of decomposition in yeast is attributable to a determinate catalysing temperature.

Complex organic substances are easily transformed by a change of temperature, and this transformation is easily communicated to other organic substances, with which they are in contact. We are entitled to hold this as positively proved. According to our observation, therefore, we place the primary source of chemical action,—proceeding from complex organic substances, and transferred to others,—not in those substances themselves, but in the temperature. We call the temperature catalysing, then, in the same sense with Berzelius, as having the power of modifying the chemical forces, which are hidden in the elements, and which unite them into one whole—strengthening those forces in some cases, and weakening them in others, so as to disturb the equilibrium, and produce new substances,—just in the same manner as spongy platinum excites hydrogen and oxygen to enter into combination, as sulphuric acid converts the elements of alcohol into water and oxide of ethyl, and as the same acid converts sugar into the humic and formic acids.

The chemical forces which can be excited in inorganic substances by this decomposition of organic bodies, are sometimes governed by laws, different from those which usually obtain

in mineral substances. If, for instance, sulphate of soda, of which the elements are firmly combined, be exposed to the influence of a putrefying substance, carbonate of soda and sulphuretted hydrogen are the results. The carbonic acid is produced by the fermentation of the substances in putrefaction, but, contrary to all ordinary chemical laws, the sulphuric acid is decomposed; it loses its oxygen; and at the same time the water is decomposed, its hydrogen combining with the sulphur. The decomposing action of organic substances is thus transferred to those which are inorganic, and even alters their ordinary chemical forces. (Treatise on the Waters of Amsterdam. 1826.)

If we see such a transformation taking place among strongly combined atoms, then the atoms of organic substances, loosely combined, may, by the same means, be still more easily transformed. This remark applies especially to such as are so feebly combined as to be immediately separated from each other, and made to assume a new arrangement by the slightest action, in which they are involved. This transformation takes place the more easily, because the organic chemical forces act upon others of a similar kind. Hence the easy conversion of sugar into alcohol and carbonic acid, or, in other circumstances, of sugar into lactic acid and into mannite, of alcohol into acetic acid, &c.

It appears from the variety of changes to which sugar is subjected by different agents (converting it into alcohol, ulmic, oxalic, and saccharic acids), that its elements are very loosely combined—more loosely, indeed, than the elements of many other substances. We perceive something similar in oil of cinnamon. New products are continually formed in this oil by the influence either of the air or of different acids—namely, hydruret of cinnamyl, cinnamic acid, and a great many resinous substances. In every case, the elements of sugar persist in their combination till decomposed by some force. Thus in the decomposition of sugar a force must be subdued. In the alcoholic fermentation, the force by which this is effected proceeds from the yeast, but is undoubtedly to be ascribed originally to heat. Heat is the pulse of life in the chemical

changes of bodies, and has thus an unlimited influence upon their chemical combination.

Substances containing nitrogen are most liable to that kind of decomposition, during which the decomposing action is communicated to others also. Nitrogen has a strong tendency to extricate itself from combination, owing to its character of indifference (Liebig). Explosive bodies contain nitrogen—for example, the iodide of nitrogen, and the fulminates. It is only with hydrogen that it eagerly combines, forming ammonia. The chemical equilibrium of the elements is disturbed from the very moment that the production of ammonia commences, and then the action may be transferred to other substances—the fulminates, and hence their rapid decomposition. Organic substances containing nitrogen, if in contact with water, produce ammonia, and in consequence of the formation of ammonia, the carbon and oxygen combine into carbonic acid.

Thus yeast, as well as other substances containing nitrogen, requires water to produce fermentation—that is, first, to produce ammonia and carbonic acid, and afterwards to excite thereby a new disturbance of the chemical forces in other substances. The decomposing forces arise from the decomposition of water and of organic matter,—from the formation of ammonia and carbonic acid. Liebig gives an interesting proof, that those substances, which can be wholly changed into ammonia and carbonic acid, may also be decomposed with great facility. The cyanic acid belongs to that class. When dissolved in water, it is suddenly decomposed into carbonic acid and ammonia.

1 cyanic acid	+	3 water	=	1 ammonia	+	2 carbonic acid
NC^2O	+	3HO	=	NH^3	+	$2CO^2$

One equivalent of carbonic acid (CO^2), passes off with effervescence, and the water retains carbonate of ammonia (CO^2 and NH^3) in solution. Complex organic substances are decomposed the more easily, the nearer they approach to a combination, which on decomposition can produce ammonia and carbonic acid. Such, according to Liebig, should be the case with substances which produce fermentation. The action of

alkalies upon them proves, that they either contain, or easily produce, ammonia, for the alkalies all liberate ammonia from those substances, viz., from albumen, fibrin, &c. But the composition of these latter substances differs remarkably from that of bodies, in which the carbonic acid represents the principal part, after the ammonia is abstracted.

For instance, if from 1 equiv. of protein, $C^{40}H^{31}N^{5}O^{12}$
We take..... 5 equiv. of ammonia, $H^{15}N^{5}$

There remains.....$C^{40}H^{16}$ O^{12}

The composition of this remainder is very different from that of carbonic acid.

These substances, however, absorb oxygen very easily on decomposition, a fact which has recently been proved of fibrin and albumen. (Scheikundige Onderzoekingen, Deel I.)

When sugar is brought into a state of fermentation by the influence of a moderate temperature (59°–67° Fahr.), and of yeast, alcohol and carbonic acid are always the products; and so with many saps containing sugar; for instance, the sap of fruits, beet-root, carrots, onions. But if these are made to ferment at a temperature between 97° and 104° Fahr., other products are formed. The albumen and gluten of the sap are then wholly decomposed, so that all the nitrogen remains in the liquid in the form of ammonia. With this alteration in the influence, lactic acid, mannite, and a gum-like substance are produced from the sugar, instead of alcohol and carbonic acid; gases at the same time being evolved. Thus it is evident, that the decomposition of the sugar entirely depends upon the state of the gluten and albumen in the sap of plants, which bodies are both changed into the chief constituent of yeast, during the alcoholic fermentation. It is also evident, that yeast, if subjected to a decomposition different from the ordinary kind, forms entirely new products, which are not at all analogous to those formed by the alcoholic fermentation. Hence it is clearly proved, that the general idea of the molecules being put in motion, is not sufficient to explain the formation of alcohol and carbonic acid from sugar. That motion on the contrary, must be of a peculiar nature, and such

as to affect the molecules of sugar in one determinate mode, for the formation of alcohol and carbonic acid. The alcoholic fermentation can be produced only by the most simple transformation of yeast. This transformation consists in the production, first of acetic acid, then of carbonic acid, and, probably at the same time with the latter, of ammonia. If this transformation be checked, yeast has not the power either to excite or to maintain fermentation. The power of yeast is destroyed, or paralysed, by drying it highly, by chloride of mercury, by nitrate of silver, by sulphurous acid, by creosote, &c. Yeast is also incapable of producing, or at least of originating, fermentation, without the aid of the oxygen of the air; for if the air be completely excluded, no fermentation takes place.

Very incorrect ideas have been formed, as to the peculiar character of yeast. From several analyses which I have recently made, I am quite convinced that it is a little cellular plant, consisting of isolated cells. These little plants are utricles of a substance, nearly approaching to cellulose—woody fibre—in its properties and composition, though in some respects it is different. Its composition is $C^{12}H^{10}O^{10}$.* It is insoluble both in cold and in boiling water; it is not converted into xyloidine by nitric acid, but it is readily changed into humic acid by hydrochloric acid, and is easily soluble by strong caustic potash, at the ordinary temperature. Its composition cannot by any means be reduced to that of cellulose.

These utricles contain a protein-like substance, which is neither gluten—for it is insoluble in boiling alcohol—nor albumen—for it is with great difficulty soluble in acetic acid. In boiling water it may be pretty easily obtained in such a state, that it may be regarded as a highly oxidized protein. Thus—

Substance separated from yeast,	=	1 protein	+	8 oxygen	+	6 water.
$C^{40}H^{37}N^5O^{26}$	=	$C^{40}H^{31}N^5O^{12}$	+	O^8	+	$6HO$.

* Scheikundige Onderzoekingen. Deel II.

	Found.	Atoms.	Calculated.
C	45.00	12	44.92
H	6.11	10	6.11
O	48.88	10	48.97

It contains no nitrogen.

In these utricles, however, this protein exists in such a state, that its composition approaches to that of fibrin, albumen, and casein ;*—that is to say, when it was extracted by acetic acid, and precipitated by carbonate of ammonia, its composition appeared to be analogous to that of these substances.†

The substance, approaching to cellulose, which forms the bag or utricle of the yeast plant, does not assist fermentation. During that action, the protein compound penetrates exosmotically through this membrane, the utricles decrease in bulk, contract, and at last remain behind in the form of collapsed, wrinkled globules, much smaller than they originally were. The protein compound, when expelled, soon undergoes decomposition, to which, at a certain temperature, it is exceedingly liable. It leaves nothing behind, but ammonia and a quantity of extractive matter which has not yet been sufficiently analysed. Thus—

From protein, ...	$C^{40}H^{31}N^{5}O^{12}$
Take ammonia, ...	$H^{15}N^{5}$
There remain, ...	$C^{40}H^{16}\ O^{12}$

Thus, it is evident, that heat is the primary cause of the phenomena of fermentation. The protein compound in yeast, a very complex body, has, in common with many other substances, such as hydrate of deutoxide of copper under water, &c., a temperature which forbids its permanence under water, and induces decomposition. This decomposition is transferred to the sugar, and resolves it into carbonic acid and

* Scheikundige Onderzoekingen, Deel II.

	Found.	Atoms.	Calculated.
C	43.35	40	43 65
H	6.56	37	6.50
N	12.68	5	12.64
O	37.41	26	37.12

† Scheikundige Onderzoekingen, Deel II.

	Found.
C	54.35
H	7.04
N	16.03
O	22.58

The sulphur and phosphorus have not been determined.

alcohol. During this decomposition, especially at the commencement, a small quantity of oxygen is absorbed. This absorption is not the cause, but the first effect, resulting from the decomposition of the protein compound which exists in yeast. Thus, all that has been stated as to the chief constituent of yeast, holds good also with respect to yeast itself, provided we regard the cellular membranes of the yeast globules as having no influence whatsoever upon fermentation, but as being only the vessels to contain the protein compound. They are left behind insoluble, when fermentation is finished.

During the fermentation of sugar, by means of yeast, part of the latter is decomposed, though its component parts contribute nothing to the formation of alcohol; neither do they, to any perceptible extent, add to the quantity of carbonic acid produced. For Thenard has found that 100 parts of sugar yield 51.27 of carbonic acid, and 52.62 of absolute alcohol, making together 103.89. One equivalent of water, however, is combined with sugar when crystallized—$C^{12}H^{11}O^{11}$—which thus gives nearly the same amount. In my experiments, 20 parts of yeast, which had caused the fermentation of 100 parts of sugar, left behind 13.7 parts of insoluble matter, which being again put in contact with sugar, left behind 10 parts of insoluble matter, which had no further power of producing fermentation. It has been elsewhere stated, that the yeast is also decomposed during fermentation. But a very small quantity of yeast cannot bring a large quantity of sugar into fermentation; while on the other hand, the decomposition of the yeast still continues, after the transformation of a small quantity of sugar into alcohol and carbonic acid (Liebig).

This power, either of yeast, or of animal matter, to resolve sugar into alcohol and carbonic acid, has been justly traced by Liebig to the same principle with many other decompositions. If, for instance, the fresh urine of the horse be evaporated and saturated with an acid, hippuric acid is produced; but if the urine be kept for some days, the product is not hippuric, but benzoic acid. If fresh human urine be saturated with nitric acid, we get nitrate of urea; if the urine be putrescent, we

have carbonate of ammonia. Amygdaline is changed by yeast and sugar into prussic acid. (We must persist in calling the action of emulsine upon amygdaline, catalysis, till it be ascertained that emulsine is in a state of decomposition, and immediately communicates that to the amygdaline.) If mallows be macerated in lime-water, we get asparagine after evaporation; but if the solution be put in contact with yeast, we get aspartic acid, combined with ammonia.

A great many organic substances, when exposed to a fixed temperature and to moisture, are decomposed into new products, which can be formed by ordinary chemical means also. For instance, the natural change of woody fibre into humic acid and other substances, may be likewise produced if sulphuric acid be made to act upon woody fibre. It is not a real fermentation, but a transposition of the elements, analogous to that which takes place in yeast, which is transferable to others. If wood undergo decay while lying in water, which contains salts of sulphuric acid and iron, sulphuret of iron is deposited upon the solid substances, whilst the rotting wood is converted into humic acid. This sulphuret of iron is produced from the sulphur of the sulphates, and from the iron of the iron salts. Some substances very rapidly undergo the alteration, which causes the production of humic acid from woody fibre. Tannic acid, for instance, if exposed to the air, is very quickly converted into apotheme of tannin; and in like manner extractive matter is converted into apotheme, by the influence of the oxygen of the air and a more elevated temperature. It is a similar transformation to that which takes place in substances containing nitrogen, such as yeast, &c., but of course it is incapable of producing any ammonia if they contain no nitrogen. During this transformation, oxygen is always absorbed, and sometimes only one of two new substances are produced; such as when acetic acid and water are formed from alcohol by the agency of the oxygen of the air. Thus—

1 acetic acid and 3 water = 1 alcohol and 4 oxygen.

$$C^4H^3O^3 + 3HO = C^4H^6O^2 + O^4$$

By the oxidation either of tannin or of extractive mat-

ter, however, carbonic acid is also produced, and equal in volume to that of the oxygen absorbed (De Saussure). The elements in such substances are very loosely combined, and tend to produce other substances, which combine more intimately. They have thus a kind of tendency to act externally, and eagerly attract all the oxygen with which they are in contact. This state, which is like that of hydrate of protoxide of iron, hydrate of protoxide of manganese, sulphuret of potassium, and many other inorganic substances,—we indicate by the expression (which is too limited) of tendency to oxidation. The greater number of organic chemical substances are transformed in consequence of this tendency. Such is the case with the solutions of vegetable acids in water, which, if exposed to a certain temperature, can produce a series of new substances, such as citric acid, tartaric acid, &c., and new substances even of an organic nature, such as mouldy plants. If the substances be of a complex character, they are still more easily transformed. Such is the case with wood, which in certain circumstances is subject to very rapid decay—dry putrefaction—caused by the albumen which it contains; and with many other substances. The alkalies, especially, are capable of promoting in some substances this conversion of elements. Gallic acid, for instance, when in contact with an alkali, is rapidly changed into a brown matter; so salicylite of potash is changed into acetic and melanic acids, by absorbing 3 of oxygen (O^3).

Fat oils and other fatty matters in this manner produce neither a mixture of different substances, nor carbonic acid, but a fatty acid. Almost all the volatile oils form resins, the products of oxidation by the air. Other examples are afforded in the transformations of orcine, phloridzine, &c., when in contact with air and ammonia, producing blue colours from white substances (see below). And so in the transformation of protein with 4 of oxygen into humic acid and ammonia. Thus—

One of protein, with four of oxygen, ...	$C^{40}H^{31}N^5O^{12}+O^4$
Are equal to 1 of humic acid,.....	$C^{40}H^{15}\ O^{15}+HO$
And five of ammonia,.....	$H^{15}N^5$.

I repeat, that all these transformations correspond to such ordinary phenomena in inorganic chemistry, as the oxidation of iron, potassium, &c., in the air.

This transformation has been compared to *combustion*; and whether hydrogen only, or carbon only, or both be combined with oxygen, it has been called combustion. It does indeed resemble combustion. But there is this difference between such a transformation of substances and combustion, that the latter is a complete conversion, effected by a more elevated temperature, while the other phenomena are produced by a mere disturbance in the equilibrium of chemical forces. These forces are modified, while the vital functions of the animals or plants, to which the substances belong, are in action; they are still present in certain circumstances, in which they are not sensible—as when the body is dry, and is kept at a low temperature; but they are disturbed by heat and moisture, especially the former, so as to make room for other forces. Among these new forces, the tendency of hydrogen and carbon to oxidation then appears. These forces come into operation as soon as the others are at rest. They come into full operation if a great disturbance is effected by powerful causes, such as when a burning substance is brought near the organic one; they are, however, but partially brought into operation, if a different set of atoms of carbon, hydrogen, or oxygen meet each other in such a proportion as to produce an intimate combination again. This is clearly illustrated by the change of sugar into alcohol and carbonic acid.

It must not be thought, however, that this power of affecting substances resides peculiarly in oxygen. If our atmosphere consisted either of chlorine, or of vapours of bromine only, the power of these substances to disturb a chemical equilibrium, or to form promptly, in case of a disturbed equilibrium, a combination with substances present, would be much greater than that which we now perceive in oxygen. All these phenomena of oxidation, either in organic or inorganic substances, ought not therefore to be classed as a determinate and peculiar series. They must be referred to ordinary chemical action, dependent in a great measure on the

influence of the circumstances in which a substance is placed. This action is always terminated by the operation of the chemical tendency, the production of a state of equilibrium.

The peculiar forces of the elements must, therefore, be classed among the principal causes of the conversion of organic substances into others, accompanied by the attraction, for instance, of oxygen. This tendency to combine with oxygen is not exhibited by free carbon and hydrogen at the ordinary temperature, but may be excited in both by heat, and in hydrogen also by spongy platinum. We see these forces very active in potassium and sodium, in phosphorus and many other substances. Hence it appears, that such substances act in the same manner (*i. e.* attract oxygen), without the aid of any new external circumstances, as carbon and hydrogen do when under combustion, or when accompanied by the conversion of organic matters. As soon, therefore, as carbon and hydrogen cease to be influenced by those chemical forces which modify them in the organic kingdom, they yield to what is originally their most powerful tendency ; they combine with oxygen in the same way as the nitrogen of yeast combines with hydrogen and forms ammonia. So far, therefore, as the arrangement of the organic molecules is changed, when bodies begin to decay or undergo any similar transformation, the change depends partly on that primary tendency of the elements, partly on the possibility of forming such new and intimate combinations of the elements, when otherwise arranged, as cannot be again disturbed in these circumstances, but can be decomposed only by more powerful causes.

The alteration in wood which is called mouldering, does not essentially differ from putrefaction. So far, however, it is different, that during putrefaction, hydrogen combined with carbon is given off in the form of gas, while in the former case only oxidation, either of carbon only, or of carbon and hydrogen, takes place. Hence it appears that, properly speaking, in mouldering the elements slowly obey their most powerful tendency, yielding to the strongest forces which they possess ; and on the other hand, that the formation of wood is the effect of a chemical action in an opposite direction.

The question is, whether during decomposition the organic forces grow weaker of themselves, permitting the elements to obey their primary tendency,—or whether causes must exist by which these organic forces are made weaker? Neither is improbable. Everything which ceases to be subject to the vital principle, becomes incapable of being stimulated by the vital forces;—it is placed in other circumstances; and as the products of the vital functions are different from the products of inorganic nature, in consequence of the very difference of the circumstances in which the elements are placed, so the products of substances, deprived of vital influence, must also greatly vary with circumstances. Hence it may happen, that the forces present in organic substances, when deprived of the vital influence, may disappear of themselves. The impression they had at first received is changed, modified, obliterated, and therefore the effects can no longer be the same. A substance persists in the state into which it was first put, according to the law of inertia; but the maxim, *sublata causa tollitur effectus*, is of equal value. The vital action, which we shall express by the collective name of circumstances, confers a certain tendency upon the molecules, which in many substances disappears whenever the molecules are withdrawn from its influence.

If but a small disturbance of chemical equilibrium has occurred, that is to be regarded as a focus or centre, from which the action extends. A small piece of mouldy wood infects a whole mass, acting in the same manner as yeast in fermentation.

What is the cause, to which this disturbance is attributable? There is proof that it is caused by temperature; neither fermentation, nor putrefaction, nor chemical action, taking place without a determinate temperature. But though this temperature be present, another substance is required to excite such actions in a certain degree. In every kind of fermentation, this disturbing property, it has been proved, is possessed by oxygen. The first phenomenon observed either in a fermenting or in a putrefying substance, is the absorption of oxygen. Without oxygen no putrefaction, no fermen-

tation takes place. This has been ascertained by Gay-Lussac. He kept the sap of grapes for some days over mercury; it did not ferment, but the introduction of one bubble of oxygen was enough to originate fermentation, which then proceeded spontaneously. A single bubble is thus required to bring a force to the sap of grapes, capable of disturbing in a small part of it the organic forces excited by a certain temperature. In the other parts, disturbance is effected by the new products in their turn, and is transferred through the whole mass, so that a decomposition of sugar and water into alcohol and carbonic acid takes place.

Upon this principle the preservation of meat, vegetables, &c., in vessels exhausted of air—generally by ebullition—is founded; so is the method introduced by Appert, of boiling vegetable saps in bottles, well corked, for the purpose of taking away the oxygen of the small quantity of air left behind, and of uniting it with part of the substances; and also for the purpose of disturbing by the ebullition part of the chemical forces, especially those in the dissolved albumen, which becomes coagulated when boiled. On the same principle depends the sulphuration of sweet wines or of saps of fruits, by the application of sulphite of potash, the sulphurous acid (SO^2) being easily changed into sulphuric acid (SO^3).

This attraction of oxygen is very much promoted by alkalies, though we know not how. But it is perceived in orcine, phloridzine, and salicylous acid. Alcohol, if it retain any alkali in solution, produces acetic and formic acids, besides a brown substance; absorption of oxygen being a uniform accompaniment. A substance which is easily decomposed, also readily changes alcohol into acetic acid, with absorption of oxygen. Hence alcohol is, in like manner, changed into acetic acid by a little honey, malt, beer, or acid wine, if exposed to the air. On this principle depends the method of preparing vinegar by the quick method now practised in Germany. The substances added begin first to decompose, and when in that state communicate to the elements of alcohol the tendency to transpose themselves also, and to assume a new order in connection with the oxygen of the air (Liebig). Some orga-

nic substances, however, if merely present, can act here also by the forces which proceed from them without being themselves altered; and a real catalysis may thus take place. This appears from what occurs when vapours of alcohol are brought in contact with spongy platinum, the supply of air being imperfect. The spongy platinum then becomes hot; water and aldehyd are produced, with absorption of oxygen; the spongy platinum, however, taking no part in this process. If free access be given to the air, acetic acid and water are produced. Thus the same, or some similar force, resides in the spongy platinum, as in the substances by which alcohol may be changed into acetic acid, according to the method of Schuzenbach, when these substances are decomposed after being mixed with the alcohol.

The formation of saltpetre is regarded by Liebig as an analogous process. It is a known fact, that organic substances, which contain nitrogen, can in certain circumstances produce nitric acid, which combines into a nitrate with any base that is present. Ammonia results from the putrefaction of organic substances containing nitrogen, and passes off in the form of a carbonate. The nitrogen combines by preference with hydrogen, and never directly with the oxygen. It may, therefore, be a question, how it happens that nitric acid is in this instance formed from the combination of nitrogen and oxygen?

The presence of a base, especially of some alkali, is indispensable to the formation of saltpetre. From the nitrogen, ammonia is first obtained by combination with hydrogen, and this is afterwards changed into nitric acid,—the hydrogen of the ammonia combining with the oxygen of the air to form water, and the nitrogen with the oxygen to form nitric acid, which is united with the base into a nitrate. When organic substances are decomposed by oxide of copper, deutoxide of nitrogen—if the organic substance contain the nitrogen in the state of ammonia—is always formed; but if a compound of cyanogen be burned in oxygen, the carbon only is oxidized, and the nitrogen is liberated without the production of nitric oxide. Thus nitrogen, when alone, is not combined with oxygen but only when present in the state of ammonia (Liebig).

During the nitrification, therefore, nitric acid is formed, because the oxygen of the air produces water and nitric acid at the same time from the ammonia, and because these two substances mutually promote the production of each other, while *in the nascent state*. Hence it happens, that during nitrification, the animal substances contribute but the smaller part of the nitrogen contained in the nitric acid produced, while the greater part is absorbed from the atmosphere; and so the organic substances are the chief means whereby the nitrogen of the atmosphere is changed into ammonia, which is afterwards decomposed with absorption of oxygen into water and nitric acid. This is fully proved by the nitrification which takes place without organic substances in putrefaction. A great deal of nitrate of lime is found upon old walls, and in all porous substances which have been long exposed to the atmosphere. In such porous substances ammonia is not only condensed, but produced from the air, and afterwards converted into water and nitric acid. (See *Arable Soil*, below.)

On these principles, relative to molecules in motion, for which we are indebted chiefly to Liebig, several interesting questions in science are explained.

The primary cause, however, of that motion may thus be briefly described. Every chemical molecule possesses the property of combining with others; such combination is an effect of molecular tendency elevated to a determinate degree. Tendency, producing combination, arises from various circumstances. The presence of a third substance, electricity, light, heat, and vital force, give to the combination a determinate direction—the last producing, for the most part, complex substances, which are of a peculiar character, because it is generally difficult to obtain an artificial imitation of those circumstances. Ordinary chemical operations are almost uniformly more simple. The substances produced differ, because the circumstances differ. Temperature is a powerful exciting cause of the chemical tendency which effects combination. To that tendency we must look for the primary and principal cause of what may be called molecules in motion, or, in other words, molecules in the act of transposition, possessing a capacity

for chemical combination, both of which qualities are indicated by the expression chemical tendency.

By spongy platinum, by glass at a temperature of 572° Fahr., by sulphuric acid, by any burning substance, by yeast, by a piece of rotting wood, actions are produced in chemical substances, attended with consequences which are characterised as chemical, *i. e.*, with combination or decomposition of substances.

Whatever is affected by one of these substances, must be susceptible of such influence. This is what we have called chemical tendency. The excitation of that susceptibility is equivalent to the elevation of this tendency to a determinate degree.

The object of science is to determine the influence of each circumstance. The knowledge of this influence is the basis, on which all other knowledge of the cause of combination and decomposition in substances is founded. The term *circumstance* is as yet only a collective one, comprehending very different things. The reduction of all these to their proper places in science we can expect only from future times.

§ 2. Organic Forces.

A. Connection between Organic and Molecular Forces.

All vegetable and animal substances are composed of those bodies which in chemistry are called elements, and which combine with each other in very different ways. The question now to be considered is, whether the organic forces, which operate in the organic kingdom, depend either in whole or in part on the molecular forces of the elements. This is indeed a question difficult of solution. We shall see how far science, in its present state, enables us to reach a satisfactory result.

If we assume, that an organic whole is governed by a general force called vital force, then we ascribe to that whole something which is not learned from observation. We perceive an aggregation of phenomena, which we comprehend

in a general idea, expressed by the term *life*; but that idea is a concrete. It consists of a multitude of parts. The function of every organ, though a function of life, has an individual existence, in some respects separate from the aggregation, in others not. The function of the liver is not dependent, and yet is dependent, on that of the kidneys;—not dependent, because the liver has within itself the power of secreting the bile, with the requisite organs;—dependent, because any great disturbance of the function of the kidneys influences, and may even prevent the secretion of the bile. The idea of health implies, as the principal condition, an undisturbed function of each organ and of the whole. The idea of life implies, as the principal condition, the exhibition of the chief phenomena, the subsistence of the chief actions, proper to this whole.

The entire organism, and consequently each organ, each part of any organ, consists of elementary substances, which not only are individually supplied with indestructible forces, but may possess these under very different modifications. Oxygen, hydrogen, carbon, nitrogen, iron, sulphur, phosphorus, iodine, are the substances which by mutual combination produce organic bodies; but to these are added a great many other substances, which are seldom wanting in living organic bodies. A great many acids, bases, and salts, are there present, which are just as indispensable to the existence of organic substances, as the eight elements above mentioned. Albumen, for instance, is an albuminate of soda; casein is a combination of protein with sulphur and phosphate of lime;—in a word, the intermixture of substances in the organs, and so in the organism, is not a simple but a complex one.

All those elements and compounds are severally accompanied by forces of their own. Their materiality is by no means to be called their chief characteristic, but that by which matter is governed, *i. e.* its peculiar force. They all manifest themselves as adapted for mutual combination, and appear after such combination as new substances, of which the forces are again modified, and applied by the chemist to produce new combinations.

If we pass in review the substances present in the organic kingdom, we perceive an endless series of combinations from either two or three or four elements only. This is enough to show, that there is an unlimited capacity for modification in the primary forces which operate in the elements. The influence of one element upon another is thus unlimited also. A slight difference in the state of an element is sufficient to give it the appearance of a new, an entirely peculiar, substance, as compared with the other elements. Let us take, for example, starch, gum, sugar, acetic acid, glucic acid, inuline. All these are composed of the same elements, taken in the same proportions. Thus they consist severally in equivalents of

	Carbon.	Hydrogen.	Oxygen.	Water.
Starch,	12	9	9	+ HO
Gum,	12	9	9	+ HO
Sugar,	12	9	9	
Acetic acid,	$\frac{1}{2}$ × 12	9	9	
Glucic acid,	$\frac{2}{3}$ × 12	9	9	—1½HO
Inuline,	2 × 12	9	9	+ 2HO

The carbon of one of these substances is no doubt equal to the carbon of any of the others, in so far as it exhibits the same properties, if separated from its combination. But it is incorrect to suppose, that the carbon, hydrogen, and oxygen in sugar are identical with those in acetic acid, for there is a great difference between sugar and acetic acid, and we cannot attribute this difference to anything, but to the difference of the forces by which the same substance is governed. Thus, the carbon, hydrogen, or oxygen is not in any two cases supplied with the same properties. They assume in each substance a peculiar form. The general idea comprehending carbon, hydrogen, or oxygen in sugar and acetic acid, must therefore be modified, because the forces peculiar to matter must necessarily be modified, as matter is itself unalterable.

This will appear clearly, if we consider the combinations of carbon with hydrogen. If we supposed the carbon and the hydrogen in C^5H^4, $C^{10}H^8$, $C^{15}H^{12}$, $C^{20}H^{16}$, to be always the same, we should be constrained to assume the identity of

the substances, and any distinction would be impossible.* Among the elements we know a considerable number which,

* The term *impossible* here used appears to me to be too strong. It restricts more than is necessary the powers of the elementary bodies to form compounds possessed of different properties. If into the simple combination CH one of the elements, say C, enters in two several allotropic states, C_a and C_b, we can readily understand that C_aH and C_bH would or might be different substances, the peculiar properties of which arose from the peculiar state in which the C existed in each. This is Mülder's view, generalized from the very interesting facts contained in Berzelius' paper upon the combinations of sulphur with phosphorus, to which he subsequently refers. The idea is very simple and very beautiful, and throws a new light upon the combinations of the organic kingdom.

But how do the allotropic states of the elementary bodies themselves arise? It is the effect of circumstances, which are special for each state, upon the forces of *cohesion* which reside within the similar molecules. Of course we cannot describe the way in which different circumstances act upon the molecules so as to produce these different states. It may be that under certain conditions the forces become stronger in a given direction, and cause the molecules to unite in that direction rather than in another. And that such an arrangement, by different sides, or at different distances, does sometimes take place among the elementary molecules, is shown, I think, by the fact, that in their several allotropic states, carbon and sulphur crystallize in different forms.

Now, if a new and different arrangement of the molecules cause or accompany a new allotropic state in the elementary body, may it not be so also in the compound body? If C_aH and C_bH be different substances, because in each the elementary *molecules* of C are in a different state of arrangement, may not $C^s_aH^s$ and $C^s_bH^s$ be different respectively from C_aH and C_bH, because of (or in connection with) a new arrangement of the *equivalents* of which they severally consist?

We thus recognise two causes of diversity among isomeric and polymeric bodies.

1° The different allotropic states of the elementary bodies, these being probably caused by a change in the relative positions or distances of their molecules.

2° A new arrangement, in distance or position, among the *equivalents*, whether of simple or compound bodies, the allotropic states of the elements remaining the same.

3° Both of these causes may operate together. Some of the equivalents of C or H may be in one state, some in another, and they may arrange themselves in many different ways, so as in a complex body like protein to produce numberless diversities or modifications in appearance and properties, the ultimate chemical composition remaining the same.

In other words, we may have an *allotrope* of the elementary molecules, an allotrope of the compound equivalents, or a combination of the two.—*J. F. W. J.*

without entering into any combination, present an entirely different appearance, in consequence of but a slight difference in the circumstances under which they are placed. For example, phosphorus becomes black when heated and then suddenly cooled; and by means of a red heat merely, silica is so modified, that the substance, after and before the application of such heat, might be taken for two different substances, if we looked to its properties only. The interesting experiments recently made by Berzelius, as to the allotropic character of phosphorus, have opened a new path for scientific investigations. If the *simple* substances can assume the permanent appearance of unlike bodies, without forming any combination, their compounds can do so much more. And such an assumption of other characters must take place in all cases, in which no other mode remains of explaining the diversity of the compounds, than in the supposition of a real difference in the component elements themselves.

If we apply these principles to the known compounds, a field of boundless extent is opened to our view. What we call protein in animal chemistry, is a substance which, we know, is composed of $C^{40}H^{31}N^{5}O^{12}$, which is insoluble in water, alcohol, or ether, but soluble in alkalies, whence it can be precipitated by acids; and which yields ammonia when acted on by powerful bases, &c. But what meaning do we attach to all this? What conception do we form from these considerations of the substance itself? We have a mere idea of distinction, in comparison with other substances which have another atomic composition, and are soluble in water, alcohol, or ether, which in other words possess different properties. But as little ground have we for supposing, that protein is the same in the very different modifications to which it is subjected in the bodies of animals, as we have for saying that the carbon in the sugar and in the acetic acid is governed by the same forces. The carbon in these two substances cannot therefore be comprehended under the same idea.

It is said in physiology, that in the embryo of the egg there is nothing but a shapeless mass, which by decomposition pro-

duces always the same substance,—that is, a compound of protein. From this embryo, however, is gradually evolved, during the growth of the egg, a series of germs of organs, which are soon developed as entire organs, together composing the chicken. A general force is assumed—influencing that shapeless mass, the embryo, originally existing as a whole—and represented as the same with that which the complete animal possesses. Müller says: "The simple embryo, which consists of a granular and shapeless substance, is to be regarded as the potential whole of the future animal, supplied with the essential and specific force of the future animal itself."*

No idea can be less distinct than this. According to Müller, the forces, which will afterwards govern the organs of the chicken, should be present before the existence of those organs themselves—before the production of an organism from the granular and shapeless substance of the embryo.

If we recur to what we have stated as to the idea of force, then we see that Müller has deviated far from the true method of physical investigation. In physiology, the existence of a similar general force, governing the whole, is assumed in the fully formed organism. Respiration, the circulation of the blood, the function of the nerves, &c., are effected by one force, which is called *vital force.* This vital force causes respiration here, digestion there, the secretion of the saliva and of the pancreatic juice in other parts of the body. It maintains at once the substance of the bones, of the muscles, and of the brain. It is supposed, that this same force is modified with reference to the different organs which it influences. This idea is also inconsistent with a sound method. What would remain of the primary idea of force, if we saw force here causing motion, there effecting a chemical alteration, elsewhere producing feelings or sensations? It seems to me, that in its ordinary signification, vital force expresses an idea as incorrect, as if we supposed that one single force, differ-

* So muss man die Einfache, aus körnigem formlosen Stoff bestehende Keimscheibe, als das potentielle ganze des Spätern Thieres betrachten, begabt mit der wesentlichen und specifischen Kraft des Spätern Thieres. (Physiologie, i. p. 23.)

ently modified, operated in a battle fought by thousands,—a force which acted so as to fire cannons and muskets, cut with swords, transfix with lances, sound trumpets, and keep men and horses in constant agitation, &c. The army appears as a substantial whole, and produces phenomena. The organism, composed of the most different organs, also appears as a substantial whole, and produces phenomena. If we assume, for the latter, a single force, differently modified, as the organs vary,—a single *vital force*, by which the whole is animated,—then, to be consistent, we should assume a *fighting force* in a battle. The existence of such a vital force has by some writers been maintained, by way of distinguishing animate from inanimate nature; for in a stone there is no appearance of a general force of so singular a kind, as to assume constantly new forces according to the nature of the organ, that is, influenced by it. A prejudice in favour of living nature, as peculiarly directed and sustained by the Almighty hand, has caused every opinion which conceived of these forces as residing in the molecules themselves, to be looked upon as savouring of materialism. It was not borne in mind that, in adhering to an intricate and obscure idea of vital force, we do not at all approach to an acquaintance with the manner in which the organic world is maintained by that Almighty Being, who with unlimited wisdom created and still sustains every animate and inanimate substance. Let us then proceed to inquire what forces we must regard as existing in organic substances, and where we must commence, so as to arrive at a sound conclusion.

Let us ascend from the simple to the compound. It has been ascertained from observed facts, especially from the application of these by Liebig, that some plants* will grow, when supplied with carbonic acid, ammonia, and water, provided the bases and acids be added to these—the salts, that is—

* By saying, that *some* plants *will* grow, it is not implied that plants in general do not extract soluble organic substances from the soil, viz., humate of ammonia, crenic acid, apocrenic acid, &c. It has, however, been ascertained, that many plants can produce organic compounds from carbonic acid, water, and ammonia. (See *infra*, *Arable Soil*.)

which are necessary to every kind of plant. Now, it must be supposed, either that the plants are nourished by carbonic acid, water, and ammonia; that with new materials the plants receive new forces from those bodies; or that the plants can themselves *communicate* forces to the elements of carbonic acid, water, and ammonia. The idea of *communication of forces* is unsound; it is only what is substantial that we can communicate. Forces may be *excited*, they cannot be *communicated*.

This is fully explained by the phenomena produced by the magnet. A piece of steel possesses magnetic forces, though not magnetised. These forces are slumbering, that is, such an equilibrium exists between them, that they cannot be externally perceived. They nevertheless exist. They reside in the molecules of the iron. Three elementary substances are known, to which they are peculiar: iron, nickel, and cobalt. Every particle of these metals is possessed of the same forces, and these forces can produce that series of magnetic phenomena which science has observed. But these forces cannot be communicated to tin, lead, or silver. When we appear to communicate them to a piece of steel, we merely excite what previously was hidden in it—we separate what had been united. In the same way, plants excite forces in the elements of carbonic acid, water, and ammonia, whenever these are absorbed, and their elements are combined in different modes, so as to form acids, bases, neutral compounds, resins, fats, volatile substances, &c. If there be only excitation from the plants, then the forces originally existed in the elements of carbonic acid, water, and ammonia: that is, though slumbering, they *are* present. Hence it results, that every transformation in plants is effected by the molecular forces of carbon, hydrogen, oxygen, and nitrogen,—the elements of carbonic acid, water, and ammonia,—the forces being excited in these elements by the plants themselves.

By the plants themselves? What does this mean? Does *the entire plant* excite slumbering forces in carbonic acid at the very moment the acid enters the plant? Or is such excitation produced by some one *part* of the plant? It is produced by the

part of the plant, with which the carbonic acid is in contact, at the moment it becomes changed, producing new and indeed organic substances by the assistance of water, or of water and ammonia. Let us take starch as an example. It is not the entire plant which produces a grain of starch from carbonic acid and water, with separation of oxygen, but a small organ of the plant. By this organ a force is excercised, exciting forces which slumbered in the carbon, oxygen, and hydrogen, or rather *modifying* the forces existing in these, so that 12 equiv. of carbon (C^{12}) combine with 10 equiv. of hydrogen (H^{10}) and 10 of oxygen (O^{10}), and from 12 equiv. of carbonic acid ($12CO^2$) and 10 of water (10HO) starch is produced—24 of oxygen (O^{24}) passing off. * Any one who imagines that there is anything else in action than a molecular force, than a chemical force, sees more than exists. Such a phenomenon is common, and it is one of a chemical nature, produced as new combinations are in the inorganic kingdom. It is only the circumstances which differ.

Are those small organs, however, necessary to the manifestation of such forces? and are those forces to be found only in plants? Certainly the different organs, which produce different substances in plants, exert peculiar forces; yet these are not entirely peculiar to those organs. Gum and sugar can be formed without the intervention of the plant, as well as in its interior; and the same is the case with the benzoic, the cinnamic, and the valerianic acids. The chemical forces, therefore, which proceed either from the minute organs of plants, when they form new compounds out of carbonic acid, water, and ammonia, or from these substances themselves, after they are combined in some manner, may be excited in a common chemical way also; and so far as this cannot be effected, an accidental, not a real difference is the cause. Every compound substance requires peculiar circumstances for its formation; that is, the forces in the elements of the compound must be excited by the influence of peculiar circumstances. Starch and cellulose have not as yet been pro-

* By this I do not mean that starch is formed directly from CO^2 and HO; we have here taken an example from a familiar substance.

duced, except in the living vegetable, and may never be so; but neither is sulphuric acid produced in plants from sulphurous acid and oxygen, nor hyper-manganic acid, nor chloride of iron, nor deutoxide of hydrogen, nor peroxide of potassium. The forces excited in the elements vary with the influence which certain agents—temperature, moisture, light, &c.—exert. By the aid of crucibles and retorts, therefore, compounds can be formed which differ from those produced by the organs of plants; while from carbonic acid and water plants can produce cellulose and oxygen, a result which cannot yet be attained by art.

Of what do these small organs, producing cellulose and starch in plants, consist? They have originally been produced in a similar way with the grains of starch itself, that is, from carbonic acid, water, and ammonia, by the operation of organs previously existing. On their production they received peculiar forces, as the grain of starch does. The difference between the organ producing starch, and the grain of starch produced, is not that the former can alone excite force, and that the latter is passive;—both are active in their turn. If starch be put in contact with nitric acid or sulphuric acid, the latter are powerfully decomposed by the starch, which itself at the same time is altered. Though starch be formed from carbon, hydrogen, and oxygen, it still exhibits, under different circumstances, a great variety of chemical tendency in its elements, inducing the production of new compounds. Starch yields gum and sugar by means of diastase; sugar may be changed into carbonic acid and alcohol by means of yeast. Alcohol is changed into oxide of ethyl by means of acids, and into haloid compounds of ethyl by means of hydracids; when brought into contact with the air, and either an organic substance or spongy platinum, it produces acetic acid; with a more elevated temperature, it produces aldehyd; by means of chlorine, chloral; and lastly, by combustion in the air, carbonic acid and water. At this point the primary elements of starch re-assume the same form in which they were originally presented to the plants, part of the carbonic acid, however, being separated during fermentation. By the combustion all the ele-

ments become fitted again for nourishing plants, and a small organ, similar to that which produced the grain of starch, may again produce starch from this carbonic acid and water.

To express briefly what we have now endeavoured to explain—no excitation of the forces of carbonic acid and water could be effected in the plant by its organs unless those forces already existed, any more than chloral could be produced without alcohol and chlorine.

To whatever organ of plants we direct our attention, all, without exception, are formed in the same manner as the grain of starch, and all have received peculiar molecular forces at the moment they were formed from chemical molecules. The notion that heterogeneous forces can excite each other is opposed to the primary idea of force. The force of gravitation cannot excite the magnetic force. It is only homogeneous forces that can set each other in action. Every decomposition, every formation of new compounds, the products of molecular forces, can therefore be effected by molecular forces alone; in other words, the small organs, which form a new compound from substances supplied to them, and which disturb the existing chemical equilibrium, can do so only through chemical forces possessed by them—through the chemical tendency possessed by their elements. This is the source of every excitation of new forces giving rise to a new combination. Further, these exciting forces proceed not from masses, but from molecules; they are molecular forces, and have therefore nothing in common with what proceeds from the whole individual. Starch is not formed by the plant, but by the molecules of the organ in which it is produced, because those molecules modify the chemical equilibrium.

This may be explained by an example. During the transformation of starch into gum by sulphuric acid, each molecule of the acid influences each molecule of starch, the latter thereby becoming gum;—the mode in which the elements of starch are combined is changed by the sulphuric acid, the alteration proceeding from molecule to molecule. The production of gum from starch in the organs of plants is similarly effected.

Wherever forces are found in organic nature, there are substances which are all supplied with molecular chemical forces. Even those singular structures, the nerves, consist of the same elements as the ordinary substances of the organic kingdom. It is thus undeniable, that the molecular forces act a chief part in the organism, so far as a change of substances takes place therein; and that no general, no vital force, should be assumed as the source of those molecular forces. Such a vital force is irreconcilable with the true principles of science, which require that nothing should be *assumed* as existing, but that every thing should be *sought for* in nature; which teach us to ascend only from an unprejudiced consideration of the phenomena to their causes, and to assign those causes only as we deduce them from the observed phenomena.

B. The Development of a Germ.

If we review the phenomena of life, caused by change of materials, we must go back to the original formation of organs —to the growth of an individual from a germ. We perceive no greater traces of the future oak in the acorn, than of the chicken in the embryo of the egg. Should we say that the acorn is governed by an oak-forming force, the embryo by a chicken-forming force? Does there exist a *general* force, which governs in particular all the molecules of tannic acid, starch, cellulose, &c., in the acorn, and all the particles of protein in the embryo of the egg? A *particular* or *peculiar* force is the active cause of *peculiar* effects; a *general* force is the active cause of *general* effects. Nobody can form any other idea of the terms. Though it cannot be denied, that in the embryo the rudiments of the future organs of the chicken are not to be found; yet we do find the materials from which the first rudiments of organs will be produced, that is, we find rudiments of rudiments. The forces which are inseparable from matter, their molecular forces, are present as well as the materials. If in these molecules there exists no capacity of becoming the germ of organs, and if in the germ of organs there exists no capacity of ultimately

becoming organs, no chicken at all is produced. This capacity, this predisposition, must be present in the molecules, otherwise the heat necessary for hatching would be insufficient to produce germs of organs in the first place, and organs afterwards. This is the only reason why the embryo of the egg will not produce an oak, nor an acorn a chicken.

As the materials differ, so do their forces. Some who concur in this conclusion are of opinion, that the granular shapeless mass, which they suppose exists in a passive state, is acted upon by a power that can only be described as a chicken-forming force in the embryo. This mass is, according to Müller, "begabt mit der wesentlichen und specifischen Kraft des spätern Thieres," (supplied with the real and specific force of the future animal). This animal, however, does not as yet exist, and not even a single organ, nor the germ of a single organ; and are we to suppose that in that shapeless mass the *peculiar forces* of the animal exist, though that animal itself does not yet exist? I must acknowledge that I can scarcely imagine a gall-secreting force in the perfect liver; and I believe that no human being can possibly conceive of a gall-secreting force in the embryo of the egg, which does not yet possess even the rudiment of a liver. This idea is also unphysical. In the science of nature, we infer that forces exist whenever phenomena are observed; but if the non-existence of the organs, by which they are produced, render such phenomena impossible, no question can arise as to such forces. No forces peculiar to the future animal, therefore, can exist in the embryo.

Let us take an example from the inorganic kingdom. If we evaporate a solution of sulphate of soda in water, we get prisms. In what form must we suppose that the sulphate of soda exists in the solution? In that of minute prisms? By no means. In that of molecules, supplied with a prism-forming force? We must reject this supposition too. There exists only a force of molecular attraction in a determinate direction, the formation of the prism being *the last result*. Between the first attraction of the molecules in a determinate direction, and that last result a great variety of states of the particles inter-

venes,—a great many forces come into action, which are present, and excited *only when* the molecules, by the position they have already obtained, cause them so to be excited in and by each other. According to the doctrine of isomorphism, the arrangement of the molecules causes the formation of the prism; for every substance composed, for instance, of MO and RO^3, assumes forms, among which a crystallographic connection exists.* But as we have no reason for imagining a prism-forming force in each of these isomorphic substances, in sulphates, seleniates, &c.; so have we none for holding, that this primary force, dependent on the position of the chemical molecules, is the only cause of all the phenomena perceptible during the formation of prisms.

Let us apply this to the substances present in the embryo. Whoever perceives in them nothing but protein and certain salts, examines that shapeless mass in a very cursory manner. Our object should be to mark what we see evolved from it, namely, compounds, which, in chemical composition, differ either slightly, or not at all, from protein; but which, nevertheless, do differ from it.

The shapeless mass begins to exhibit, here and there, very small points, that is, arranged particles. These are produced from the existing materials—their forces being excited by the increase of temperature. Without elevation of temperature, such new arrangement of particles cannot be effected; but at the same time the molecules must possess a capability of being arranged, just as those of the sulphate of soda. The first crystals of this salt cannot be formed without the evaporation of the water, &c., and without a power in the molecules of attracting each other in a determinate direction. In the embryo, this arrangement of the particles increases more and more, so as to produce a greater complication. That does not result

* MO denotes the protoxide of any metal M, or a combination of one equivalent of oxygen (O), with one of metal. RO^3 represents an acid composed of one equivalent of any radical R—such as sulphur or selenium—with 3 equivalents of oxygen (O^3). All compound sulphates, seleniates, &c., represented by $MO+RO^3$, in which M may be any one of several metals, and R any one of several radicals, crystallize in forms, which are either identical, or are closely related to each other.—J.

from the primary molecular forces, till after they are modified by those other forces which the substances received on their first arrangement. That first arrangement of the particles in the embryo, as well as the subsequent, must, of course, differ from that of sulphate of soda, because protein differs from sulphate of soda. But neither is the protein, in each of its particles, *the same protein in a chemical sense*, that is to say, yielding on analysis no other result than $C^{40}H^{31}N^{5}O^{12}$; the protein, therefore, does not always possess the same primary *arranging forces*. A minute difference of condition causes the deposition of sulphate of soda in very different forms, either with 10 equiv. of water of crystallization, or without any; the former are produced at a temperature below, the latter at a temperature above, 91° Fahr. The molecules of the substances which occur in the organic kingdom—those of carbon, hydrogen, oxygen, and nitrogen—seem to possess an unlimited power of forming mutual combinations. The number of compounds which they form, indeed, is incalculably great. That power is *inherent* in these elements; neither in the animal, nor in the vegetable kingdom do they acquire it; it is only excited therein. The diversities of form which the elements of sulphate of soda may give rise to, are very limited; but, on the other hand, the elements of protein, by their unlimited power of chemical arrangement, can originate endless diversities of combination. If subjected to chemical examination, each particle of the embryo in the egg would appear to be protein; but by such examination we could not discover the peculiar condition which makes one particle differ from another. We can no more explain this than we can the real difference between the transparent and the milky arsenious acid, between the yellow and the red bin-iodide of mercury. We perceive the differences, however, and therefore admit their existence; and so when we perceive them in reference to albumen, fibrin, casein, we are equally constrained to admit them.

Undoubtedly the differences which exist between the particles of the same organic substances are not chemical, in the ordinary gross signification, but are of the nature of those

which are connected with polymorphism. The chemist gives us but a rude result—the composition in a hundred parts, frequently not affording us any insight into either the real characters of substances, or into their real differences. Whenever such dissimilar particles come together, a compound must be produced, possessing peculiar forces, which, though dependent upon the molecular forces of the elements, are yet not determined by these alone. The new arrangement causes a modification of those primary forces. Whenever it takes place, they appear modified, and therefore indicate their presence by producing new effects. In sulphate of soda, the whole collected forces of its constituent molecules—those of sulphur, sodium, and oxygen—are still existent; and upon these alone depend its qualities, composition, and crystalline form. Sulphate of soda cannot possess other qualities—cannot become other in property—than what results from its elements, and exclusively originates in these.

Thus, then, we suppose that the molecules of the substances in the embryo are arranged, in the first place, simply, and afterwards more complexly. Not a trace of any organ is as yet perceptible, however; nor of any force, therefore, by which these organs will be governed. By the new arrangement of the particles, the molecular forces are modified anew, and this process is continuous. Although the primary forces, once united with the materials, remain the source of every action, of every manifestation of phenomena, of every chemical and organic, that is, physical, combination; they must, nevertheless, produce different effects, as the combinations become more complex. Each existing particle is the germ of a subsequent one, which is more complex; and, while the temperature necessary for hatching keeps the primary forces always excited, there is originated in the new arrangement of the particles, and also in the forces proceeding from the groups recently formed, a modification of these primary forces, which is constantly on the increase.

The whole material of the embryo in the egg is, in this manner, gradually brought within the circle of action. Then the circle is still more extended, and in its action are compre-

bended the elements of the yolk, and also of the albumen. These are erroneously called the food of the newly formed chicken, or its rudiments. In these elements there are forces also conjoined with the materials—chemical forces, analogous to those which exist in the embryo, and contributing to the production of the whole. These forces differ from those found in the embryo, not in nature, but only in direction, or in the mode of manifestation.

Thus we do not at all suppose that the molecules of the heart in the complete chicken existed in the germ as heart-molecules, or the molecules of the intestinal canal as intestinal molecules. No, but a series of successive transformations proceeds in the embryo—the production of the heart, of the intestines, of the whole chicken, being the final result. Neither do we suppose, therefore, either a heart or intestine-forming force in the germ, but a gradual evolution of new series of forces, resulting from the same primary forces of the molecules of carbon, hydrogen, oxygen, and nitrogen, and which are to be considered as so many exhibitions of new groups, produced in their turn by the causes previously in operation.

In this way, therefore, neither does a gall-secreting force exist previously to the production of a liver, nor the force which effects the circulation of the blood previously to the production of the heart and blood-vessels.

It is an impenetrable mystery how the particles of substances, both organic and inorganic, mutually combine in different modes; and after they have so combined, again form new compounds. This mystery, as regards organic substances, is not, however, greater than that which surrounds the inorganic. If any one fancies that it is more easy to conceive of the production of a crystal, than of a texture composed of fibres, globules, and cells, that is, of any organ;—of the origin of a precipitate, than of a primary fibre;—of the state in which crystallized sugar exists in solution, than of the first rudiments of organs in the embryo,—he egregiously errs. To penetrate into either is not as yet permitted to man.

To express our idea in a few words,—the elements of the

organic kingdom, carbon, hydrogen, oxygen, and nitrogen, are susceptible of endless modifications of their primary forces. For that reason they can form, with minute changes, a great diversity of products; and, by the operation of the same primary forces, they stand towards each other in entirely different relations from those assumed by all the other elements; so that they can produce a peculiar series of bodies, which are called organic substances.

C. Equivocal Generation.

Upon the principles which have been stated above, no room is left for the dispute as to *equivocal generation* and *epigenesis*. The doctrine of epigenesis has originated in the idea, that every living thing is produced from ova alone; because in these only can all the forces and germs of organs exist, which are found in the future plants or animals. The dictum of Harvey, *Omne vivum ex ovo*, has been strongly defended, and has still many supporters. On a sound view of organic nature, and of the essence of organic beings, this doctrine appears to be perfectly reconcilable with that of equivocal generation. If we consider an *ovum* as an organic molecule, or an organic body, made up of the four organic elements, combined in various groups, then the conclusion of Harvey is no doubt true. It is still true, if by an ovum we mean a molecule of a determinate kind; for this is also proved by observation. The mites of cheese are peculiar to cheese; and from certain parts of plants—fruits, for instance—peculiar fungi are produced also. It is a general rule, that from organic molecules of a given and determinate kind, only specific compounds—specific or peculiar forms, can be produced.

The term *ovum*, however, has been taken in a limited sense, to signify the germ of an individual, produced by peculiar organs only:—a germ in which everything belonging to the future animal is concentrated. Such ova, we have seen, do not exist. There is a *development*, an ascension from the simple to the complex. According to the supporters of epigenesis, an egg is such a germ as, in favourable circumstances, always produces the same species. And in reality, the sup-

porters of equivocal generation do not entertain any different idea. In their opinion, there exist certain organic substances, —organic molecules,—which are capable of evolving and forming something new; whence individual plants or animals may also finally proceed. Why may not cheese be an agglomeration of ova, that is, of molecules, from which an individual being may be produced, as from the ovum of an insect? It cannot be denied that the existence of the spermatic animalcules proves, that animals, or at least their germs, gradually growing, by merely floating in a fluid, may be secreted. What we know of the acarus scabiei, the filaria aracunculus, the echino-cocci, and a great many other entozoa, shows that they may be produced from ordinary organic molecules in the animal body, as every small organic globule of mucus, for instance, or of milk, or of pus, &c., is formed. As the germs of the spermatic animalcules are secreted animal germs, so may the molecules of casein also be the ova of mites, though these remain molecules of casein. The one idea is not excluded by the other:—an egg consists of the white and the yolk; both, however, constitute the germ of a chicken. In the very same manner the ergot of rye (secale cornutum) is produced. From the top of the same fruit, under different circumstances, a different plant arises—a fungus instead of a grass.

The idea of an ovum, therefore, coincides exactly with that of an *organic molecule*; that is, of such a molecule as consists of elements which may exhibit themselves under a change of circumstances in infinite modifications, may form new combinations, attract other elements, incorporate them, unite into definite compounds, and thus separate from other bodies with which they were originally combined. Among species of this nature, formed from organic molecules, are the mites in cheese, and the mould upon rotting fruits,—resulting from the molecular forces of the elements, like the spermatic animalcules.

Finally, the ordinary ova of plants and animals consist of nothing but organic molecules, such as those of which all organic substances are composed. They are products of or-

[redacted]

strengthened; but it is impossible to imagine the transference of a force from one material mass to another. We must first refer to this point in pausing to consider the manner in which we must conceive of the transition, into a new organic whole, of life originating in another. If animals impart vital forces to their offspring, then such forces must, no doubt, be lost by themselves. We do not perceive, however, that this takes place; on the contrary, they retain their strength, sometimes for many years, after having produced new beings, completely formed, of the same species. The tree which, for a great many years, produces fruit, and the seeds of which have, in great numbers, become full-grown trees around the parent stem, nevertheless lives as at first. A single poppy plant produces thousands of small seeds, each of which grows up to a poppy plant, equally perfect. Hence we are not entitled to admit the idea of transference of vital force, even where it is not opposed to the idea of force itself. With our own eyes we perceive the evolution of that force from its phenomena.

What part, then, bears the germ of that vital force, which is afterwards to be developed? and at what point does the development commence? It is the poppy seed which bears the germ,—a small quantity of organic molecules, different in nature from all others,—some carbon, hydrogen, nitrogen, and oxygen, combined in a certain manner into substances, which are peculiar in respect of their composition and arrangement. The peculiar quality, which distinguishes these substances from amorphous precipitates and crystals, they owe to their origin. Their elements were brought into a state of peculiar tendency, by the forces residing in the organic molecules of the plant, whose influence had previously governed them. They do not possess more than they exhibit, and they exhibit nothing but a change of their chemical composition. The seed changes its starch into gum and sugar, and so chemical forces forthwith appear, which seem to be intimately connected with the development of new forms. Another phenomenon soon succeeds, namely, the absorption of substances from without. These bring something with them:

they are not merely *substances*, but the residence also of peculiar active forces to which they owe their composition. Of these forces, some portions combine with those which are derived from the seed itself. And now, the previously existing molecule, and that which is formed from external matter, both live ;—the former through what it received from the parent-plant,—the latter through its having assumed the form of the other. This conformity arises from matter, and from the property which matter possesses, of obeying the action of forces, proceeding from the first molecule; in other words, the second molecule must necessarily be endowed with the capacity of becoming similar to the first, through the influence of the first. Thus, the second molecule did not receive its peculiarities, but these were excited in it; and so this molecule also lives as well as the first, and in its turn can take up new substances from without, and entirely assimilate them. So again, the third lives also, and thus is life gradually extended. The molecules, after being once arranged in a certain manner, give birth to new arrangements, to new forces, as we endeavoured before to explain.

From what has been stated, it will sufficiently appear, that the oak, when losing its acorns, loses none of its vital force; that an animal loses none by generation ;—but that, in both cases, the generating substances leave only certain quantities of matter, endowed with the power, first, of somewhat increasing, then of taking up other substances, and with these just so much of life as *they* afterwards manifest. Organic substances, whether called germs or food, possess properties of a peculiar kind, existing in the four elements, of which they are all constituted.

CHAPTER II.

INORGANIC, ORGANIC, AND ORGANIZED BODIES: PLANTS AND ANIMALS.

All bodies divide themselves naturally into two principal classes, namely, those possessed of peculiar organs, by means of which certain acts are performed, and those which are destitute of such organs. The former are called *organized*, the latter *unorganized*. Those substances, which are either themselves organized, or which are derived from such as are so, are called *organic* substances; those which contribute to the composition of unorganized bodies, are called *inorganic* substances.

It is not difficult to indicate the organs of an organized being, if it have them either in great number, or very much developed. Such organs, in the classes of the so-called higher animals, are the eye, the stomach, the liver. It needs no lengthened demonstration to show what is meant by such organs as these. There is no room for doubt, indeed, as to the application of the term, in even the least developed condition of organized beings; for, in general, an organ signifies an instrument by which a certain act is performed; it may be either a very complicated, or a very simple one. A mere cell, therefore, is such an organ; the only function necessary to constitute it such, being the capability of producing cells similar to itself.

This power of forming new substances is peculiar to a certain class of natural products. Such as are endowed with the requisite instruments are called organized. Each organ has its peculiar office assigned to it. But all the organs

are, besides, united into one whole: they act in combination to maintain the whole, to give it a substantive existence, to make it perform certain actions;—in a word, they form by their union what we call living beings. Living beings, therefore, are organized. Organized beings and substances either have lived, or are still living. In every thing that either has not lived or does not live, we miss those organs, which are destined either to produce new substances, or to perform certain actions; and, from the absence of those organs, their actions also are wanting in such as are unorganized.

This is the case with all minerals. Their composition, however regular as regards their form and the proportions of their elements, is such that, without the intervention of forces acting from without, the mass persists in the state in which it has once been placed. The whole is composed, in a regular manner, of parts, which are quiescent till their forces are excited by external causes. But all plants and animals have an exactly opposite character. Every thing belonging to them is in a state of continual motion, till causes come into operation, which convert that motion into rest. This motion is accompanied by a constant change in the substance of their parts, which continues even when the mutual harmony of these parts is disturbed,—the substantive existence of the individual destroyed. The animal and vegetable worlds are made up of an endless multitude of structures, which are in a state of almost uninterrupted activity;—an activity, the first indication of which is a change in their constituents, while its farther manifestations are characterised by a great variety of phenomena, all of which we include under the general name, *phenomena of life*. The regular recurrence of these phenomena we call *health*; their disturbance, *sickness*; their entire suspension, *death*; their harmonious co-operation for a common end, that is, primarily, for the maintenance of the whole, we designate *life*.

The minutest portions of an organized being consist, for the most part, of very small organs, which unite in vast numbers to constitute a substantive whole, which we call an instrument or organ. Such is the liver or the spleen. Thus, as an organized individual consists of organs, so a larger organ

consists of smaller ones; and as the actions of an individual result from the combined actions of all its organs, so again the actions of any larger organ are nothing but the combined actions of the smaller organs, by which the larger is made to appear as a substantive whole. So also in most organs, the function of the whole is made up of all the functions of all its parts combined. Thus, the simplest form of a lung is an air-cell, covered with a vascular net of arteries and veins; the smallest form of a submaxillary gland, is a small grain, into which, on one side, arterial blood enters, while the secreted saliva flows from it on another. In the same manner, the simplest form of a plant is a cell, because, if numbers of these are taken and placed together, in various orders, they produce a plant.

The size of the organs, then, by no means determines whether natural products are either organized at all, or more or less organized. The very smallest of them are still organs—manifesting themselves by certain actions, and originating phenomena, not wholly, but partly dependent on external conditions. Any substance, however, which possesses a greater variety of these organs—each of which, by themselves, or with their respective groups, perform several actions — is properly said to be *more* organized. There exists in nature an astonishing variety of such substances. Some are of exceeding simplicity, as in the lower orders of plants. Others are of a very complicated structure, possessing a variety of smaller organs, united either singly or in groups; and thus acting in a variety of ways. These latter abound in the higher classes of animals.

It need scarcely be remarked, that each organ, or each of its constituent organs, differs in substance from such as act or manifest themselves differently from them. And this difference appears not only in their substance, but also in their form—the component parts of each being arranged in conformity with the functions they are intended to perform in different classes of individuals. Hence an infinite diversity of products. They can present a new arrangement to the substances supplied to the individual from without; and hence their products are innumerable. The substances thus

produced by the organs are called *organic*. They are called organized, if they are either organs themselves, or if they contain organs; but generally organic if they are the products of organs. Organized substances, therefore, are organic substances; but organic are not always organized.

Organic unorganized substances do not at all differ from inorganic, as to the nature of the substances themselves. But they materially differ as to the arrangement of their constituents. The elements of the organic kingdom are to be met with in substances which are not organic; but wherever we find them, they are the same, and exhibit the same properties. If, however, these elements are placed in certain circumstances, they form combinations dependent on these circumstances. This tendency to combination, which exists in the elements, and which is to be looked for *within*, and not *without*—being dependent on nothing but the elementary forces, concealed, as it were, in the molecules of carbon, hydrogen, nitrogen, and oxygen,—this tendency being excited to a determinate degree under certain conditions, produces new substances. This general law, of which chemistry gives innumerable examples, is obvious in organic nature. Slight differences of temperature are quite sufficient to produce, in the chemical laboratory, entirely different combinations from the same elements. In common chemical experiments, numerous minute circumstances influence the nature of the product which results from the combination of two or more elements.

Looking at the subject in this general point of view, new combinations, entirely different from each other, must be produced by different organs from the same materials, supplied from without. And if we add to the endless multitude of different organs in plants and animals the diversity of materials afforded from without, then we shall understand how that endless series of new combinations must necessarily arise, which is formed in plants and animals, out of two, three, or four elements, and which chemistry makes known to us. In a word, every change of materials in the organic kingdom, as in the inorganic, is the result of the primary forces of the elements, and cannot be ascribed to any other source.

By the nature of those products, therefore, the nature of the actions of the said organs is more or less determined. But there are several other effects of these peculiar instruments, which go far beyond a simple change of materials. A great many living creatures are endowed with the power of changing their position at will, and possess for this purpose peculiar organs, in which the change of materials is limited to their own support exclusively—such are the muscles. They have a complete system of organs, by which they are enabled to absorb substances from without, to retain them for some time, to expend them gradually, and to employ them in the formation of new organic substances—such are the organs of digestion. They have peculiar instruments, the organs of sensation, by which certain impressions from the external world may be conveyed to a spiritual being, endowed with a power of observation, will, and even consciousness;—a being which chooses according to fixed rules, forms judgments, and draws conclusions; remembers former situations in which it has been placed; imagines new situations as if they really existed;—a being which is itself conscious, why, what, and for what purpose it exists;—a being which can investigate more or less, and admire the Cause of the universe; which recognises in itself a faint image of the Divinity, who governs both worlds and atoms;—a being which may acquire moral worth, and has a clear idea of the distinction between good and evil;—a being which is conscious that it has been created for immortality.

How surpassingly beautiful is the visible world! At one extreme of organic nature spiritual Man is placed, dwelling for a season in a godlike house, formed by a Master-hand, suited to his moral elevation, making him familiar with all nature, and with many of its beauties:—at the other extreme, the minute fungus, scarcely visible, as simple in composition as it is humble in appearance—as ill furnished with organs, as the human body is rich in them, and abundantly provided.

It is easy to distinguish between these extremes in the series of organized beings—their difference, indeed, being so obvious that we can scarcely perceive any conformity. But, whether from the one extreme we descend, or from the other

ascend—it is exceedingly difficult to draw the line of demarcation between animals and plants. The result of all the endeavours to determine this line of separation has been, that the structures of the individuals, which constitute the transition class between animals and plants, and which partake in an equal degree of the nature of both, do not enable us to reduce them to either class. They may with equal propriety be called either plants or animals.

There exists a mutual approach between the materials of which animals and plants consist, in certain determinate conditions—an approach which is really remarkable. Miguel* has described an epizootical fungus, the Isaria cycadæ; and Virey† has made us acquainted with a minute moss upon the silkworm. He has lately‡ recorded further observations, by which the Tinea lupinosa of Guy de Chauliac is reduced to a kind of mucor of the genus Mycodermata. The sporules of these kinds of plants find a fertile soil in the *scales* with which the hairy part of the head of children, &c., is covered: they penetrate into the epidermis, and in this way sustain and feed themselves. To these plants also belong the bran-like moulds, mucors, &c., which have been placed in the order of the Coniomycetes, of Nees von Esenbeck. A great many dartrous pimples belong to the class of the fungus-like mosses. The warts of the human body are classed with the gynosporanges (?) by Meynier of Ornans. It is difficult to make out, if the tubercle of the lungs be really a Cycoperdon, and the cancer a Uredo caries.

Though there is thus no uncertainty as to the characteristics proper to oaks and lions, each of them respectively producing a complete impression on the mind, so as to afford a standard whereby plants and animals may be examined and determined; nature has, nevertheless, established forms of transition, which do not admit of a fixed classification.

The attempt will, therefore, be always made in vain, to draw a distinct line of demarcation between animals and plants. Dumas is one of the last, who has tried to do so

* Bulletin, 1838, p. 85.

† Journal de Pharmacie, 1838, p. 83.

‡ Ibid. 1841, p. 703.

(Comptes Rendus, 28th Nov., 1842). He thinks that the following table of distinctive properties establishes a new system, and gives a clear idea of the difference, which we have more than once stated:—

PLANTS	ANIMALS
Produce indifferent substances containing nitrogen;	Consume indifferent substances containing nitrogen;
... fats;	... fats;
... several varieties of sugar, starch, and gum.	... sugar, starch, and gum.
Decompose carbonic acid;	Produce carbonic acid;
... water;	... water;
... ammoniacal salts.	... ammoniacal salts.
Give off oxygen.	Absorb oxygen.
Absorb warmth;	Produce warmth;
... electricity.	... electricity.
Are apparatus of reduction.	Are apparatus of oxidation.
Are immoveable.	Change their place.

He is unacquainted with the actual state of science to whom this detail is new, or appears to embody the truth. It is universally known, and will appear from what follows, that not one of these so-called distinctive characteristics will stand the test of examination.

As we are not able to draw a clear and just line of demarcation between plants and animals, neither can we between unorganized and organized substances. As soon as the functions of the organs have reached a minimum, we approach the limits of those series of substances, the most complicated of which may easily be distinguished from mineral matter—but of which the least complicated opens the way to the knowledge of another series of substances, which, being wholly dependent on circumstances, do not possess the power to represent anything, but the usual properties which are inseparable from matter.

1° The general characters of organized and living beings are, increase and growth, generation and death. Besides these properties, common to animals and plants, the former are endowed with the power of perceiving external impressions and of moving themselves at will. Schleiden* justly

* Schleiden, Grundzüge Wissentschaft; Botanik i., p. 29.

characterises animals as having a tendency in their organism, to develope their life to the utmost degree of individual separation, and thus to conceal, internally, their principal organs; that which is shown externally being, as much as possible, a uniform surface. The plant, on the contrary, bears its chief organs without, increases very much externally, and shows its beauties all on the surface.

2° If any substance is deprived of the properties common to animals and plants, then it is either an inorganic or a dead organic substance. The latter are characterised by the absence of the effects of organs, which are themselves present; the former by the total want of any organs, which either can now, or formerly could, perform any action in any circumstance whatsoever.

From the articulations of the Gallionella ferruginea of Ehrenberg* being made up almost wholly of oxide of iron, it appears that the transition from organic to inorganic substances is almost as imperceptible as that from animals to plants.†

3° *Binary and ternary combinations.* It has been thought that a clear line of distinction might be drawn between organic and inorganic substances, by stating that, among the former, ternary and quaternary combinations occur, but in the latter, only binary ones. This limit being quite arbitrary, is, at the same time, entirely un-chemical. Every one, but partially acquainted with the chemistry of organic nature, is aware that a great number of radicals have already been discovered, and that the terms ternary and quaternary, as applied to combination, were of no use after the first radical was indicated. Ether does not consist of C^4H^5O, but of $C^4H^5 + O$. The oxygen can be separated from it, and sulphur, chlorine, bromine, iodine, or cyanogen substituted. Thus we have ethyl (C^4H^5), a binary combination. This unites with oxygen, sulphur, &c.,

* Schleiden, Grundzüge Wissentschaft; Botanik i., p. 34.

† The following work may be consulted on the difference between plants and animals:—Kutorga, Naturgeschichte der Infusiores-thiere, St. Petersburg und Karlsruhe, 1839 and 1841, S. 30.

and forms another binary combination.* All organic substances are, no doubt, built up in a similar way, but the radicals of many of them are not yet known. A few years ago not one was known. Science is gradually discovering more of them, and encourages the hope that, in process of time, every organic substance will be reduced to its own radical.

4° If any distinction is to be made between organized and unorganized chemical substances, it should be stated thus:—that in the former, compound radicals exist; and in the latter, elementary ones. But is this distinction founded upon their belonging to two different provinces of nature, or upon a peculiarity in the nature of the carbon, hydrogen, and nitrogen, of which organized substances consist? The answer is obvious, for the organic kingdom is built up out of the four elements—the elements themselves being wholly independent of organic nature. It is, moreover, doubtful, whether all organic substances contain compound radicals. On the contrary, it is probable that cellulose, starch, gum, sugar, &c., consist of carbon and water. The transformation of tannic into gallic acid (see *Tannic Acid)* affords strong grounds for adopting this supposition.

5° *Juxtaposition.* Another real difference is assumed as to the way, in which organized and unorganized substances are formed. In the latter, a juxtaposition is supposed; in the former, a growth, an increase of solid matter in some of its parts. First, this distinction is not quite accurate; for horns, nails, and hair, which are all produced from protein compounds, are formed by juxtaposition. Of hair, this is proved by Dr. Van Laer beyond dispute.

* The meaning of this passage is, that ether consists of 4 equivalents of carbon, 5 of hydrogen, and 1 of oxygen; but the three elements are not united together all at once, as is represented by the juxtaposition of the several symbols in this way, C^4H^5O, forming a *ternary* compound, from which no part can be taken away without breaking the whole up. But first, the carbon and hydrogen are united together to form a binary compound, represented by C^4H^5, to which the name of ethyl is given. This afterwards combines with oxygen, and forms ether, which is *rationally* expressed, therefore, by C^4H^5+O. And the proof of this is, that the oxygen can be separated from it, and chlorine (Cl) made to take its place, forming C^4H^5+Cl, and so on.—*J.*

But let us consider this juxtaposition in the unorganized kingdom. When burned gypsum, after being mixed with water, changes into a solid mass, we look in vain for any juxtaposition. Does anything else happen in the deposition of the materials of bone, within the cells of the bones? Does not the bony matter of the skull extend itself from a centre in the form of rays? Let us take an example from the vegetable kingdom. How does the formation of wood take place? Is it not a real super-position, when layers of woody fibre are deposited against the walls of a cell? But the very same happens also in the ordinary growth of an organ. Matter does not *penetrate* into matter. If the germ of an organ, produced by simple juxtaposition, once exist, then the organ cannot increase in bulk without one particle placing itself *next* to another, and so shifting its place; and this is a real juxtaposition. This is fully confirmed by the way in which cells are produced—a subject with which, in recent times, we have become somewhat better acquainted.* There exists, however, a difference between crystals and many organic substances. The cellular and fibrous primary forms which are present in the latter, are wanting in the former; while the symmetrical forms of the crystal are not found in organic nature. The latter is just as averse to symmetrical forms, as inorganic nature is to cells and fibres. We seldom find crystallized compounds in the bodies either of plants or animals; and the substances contained in them, which are susceptible of regular crystallization, exist there usually in a state of very fine division, or of solution. In regard to thein, which is so beautifully crystallizable, we do not find a trace of it crystallized either in coffee or in tea.

If we add to this, that many organic substances, provided they are placed in favourable conditions, assume juxtaposition—for instance, tartaric acid, citric acid, &c.; morphine, narcotine, many resins, camphor, &c., which are all organic substances,—then the positive distinction between organic

* See Schwann, Microscopische Untersuchungen über die Uebereinstimmung in der Structur und dem Wachsthum der Thiere und Pflanzen. Berlin, 1839, S. 191.

and inorganic nature, grounded on this peculiarity, disappears. We may, however, state, as distinctions between organized and unorganized substances, that, generally, the former are in a cellular, the latter in a crystalline state; that the one class performs a function of which the other is not capable.

After what has been said, we must necessarily conclude that the causes of this diversity are reducible to the forces which primarily exist in the organic molecules, carbon, hydrogen, nitrogen, and oxygen, and in those of all the other elements. The four organic elements have the peculiarities, which are indicated in organic nature by their almost innumerable mutual reactions and combinations. To these elements a potency is imparted, if such an expression ought to be retained in science.

6° Finally, between plants and animals, which are both characterised by the cellular form of the component organs, there is this real difference, that cellulose ($C^{24}H^{21}O^{21}$) forms the principal part of the cellular mass in plants; while in animals the primary material is gelatine ($C^{13}H^{10}N^{2}O^{5}$), or the matter which produces glue after ebullition; and to this rule no exception has yet been discovered, either among animals or plants.

CHAPTER III.

THE ATMOSPHERE, IN ITS CONNECTION WITH ORGANIC NATURE.

THROUGHOUT all nature we perceive an intimate connection existing between different actions, the one being disturbed as soon as the other is annihilated. Phenomena are united together by a chain, of which not a single link can be taken away without throwing the whole into disorder. If water were to lose its property of being converted into vapour, every living being on the earth would die; if the composition of the atmosphere were suddenly changed, thousands of living beings would instantly perish from the earth. In some instances, many causes co-operate to bring forth one phenomenon,—to produce one substance; in others, the destruction of one substance is the condition on which another exists.

On a cursory view, nothing is more surprising than the change of forms—the alteration of appearance—to which the same substance is subjected. On penetrating farther and farther into this law of nature, nothing excites greater astonishment, than the fact that the form alone perishes; that matter changes its appearance, but is itself imperishable. We think, observe, feel, speak to each other, by means of organs composed of a mass of elements, consisting of nitrogen, carbon, hydrogen, oxygen, phosphorus, sulphur, lime, magnesia, iron, chlorine, soda, potash, and many others; but the unchanged existence of these organs is but of short duration. At every respiration they lose something, and they appropriate something again. This change is also promoted by perspiration, and by all kinds of secretion; and thus we shall not be

the same to-morrow as we are to-day. Our body is no longer the same even after the lapse of a few moments.

The organic mass, which is called the human body—the animal body of man—is a contexture of substances, which are introduced into it by certain apertures. What now forms part of the human body, some days ago belonged to the body of an animal; and, again, some weeks ago it was a constituent of plants. Whatever our human body may be to-day, it will be changed into vegetable matter possibly after an interval of but a few months.

This body derives its origin, partly from the atmosphere, and partly from the earth's surface. From the latter it is separated but for a short space, soon to return to it again. Both plants and animals are then fed from our material part; and each of our fellow-creatures, doubtless, derives support from the dust of his ancestors.

Thus, by means of a small portion of matter, *once endowed* with certain forces, the Divinity, the Author of these forces, has known how to attain, in the course of centuries, an infinite variety of ends, with which it is the endeavour of the natural philosopher to make himself acquainted.

1° It is a known fact, that nature, with singular economy, has formed the whole organic kingdom from four elements chiefly. Carbon, hydrogen, nitrogen, and oxygen are the constituents of every thing that either has lived, or is still living. Besides these, there are some so-called inorganic substances, which complete the organic whole; but it is of these four elements that the greater part of organic matter has been formed by nature. It is of importance, therefore, to consider what alterations occur in the combinations of these four elements, after they have constituted, at one time, some part of a plant, at another, some part of an animal.

2° Further, it is known that animals are nourished by plants, and thus that plants serve to connect animals with the earth's surface. Taking this point of view, the living substances by which the mere dead earth is invested with colour and the air filled with odours, become of the very highest importance. Those which are employed as food by man,

constitute, indeed, but a very small portion of the whole. Man makes use of scarce the hundredth part of the produce of the earth, and not one out of a thousand of the forms of vegetable life which grow upon it. It is, however, an indisputable truth, that without plants no animals, except the Infusoria, could exist.

3° In the third place, it is known, that what we usually call putrefaction is nothing but a change of form. A substance, which has formed part of a living being, is endowed with forces, modified in a peculiar manner, which have been excited during life, but must necessarily become again quiescent, so soon as the life of the being ceases.

According to a general chemical law, those substances have been arranged and influenced in a peculiar manner, by the peculiar circumstances in which they have been placed. Whenever, therefore, they are withdrawn from the influence of those circumstances, a great many gaseous, liquid, and solid substances appear, which taken together represent *just as many* substances, and those *the very same*, as were formerly contained in the living part. This is a new effect of the forces by which the organic world is maintained. Its destruction is its very source of life; its life, again, the cause of its destruction. When we perceive in an organic whole, that the component parts cease to co-operate for a common object, its existence as a whole—its life is at an end; a new life begins immediately to appear. It may be that the new products appear to us disgusting. Those revolting substances, however, contain the germ of the most beautiful combinations. The most splendid plant has been produced only from such substances, and can derive its support only from what has been such.

4° We may regard a fourth peculiarity as also known, namely, the value of that black layer of soil which surrounds the globe we inhabit, in many parts to the thickness of several feet. If that black crust were taken off our planet, much of what lives upon it would be destroyed or prepared for destruction. Where this covering exists, plants readily spring up; where it is wanting, many of them are either not found at all, or are found in an unhealthy condition. It is the

standing-place of the organic beings which are bound to the earth. How far it is their source of nourishment, we shall presently endeavour to explain.

5. Besides these four points, I must advert to a fifth, now sufficiently ascertained—the value, namely, of the gaseous veil of the earth, which is extended to a considerable distance from the globe; of that air-ocean which, in its fury, turns palaces into ruins, and in its calmer moments crumbles rocks into dust;—which is constantly achieving the destruction of every dead substance on the earth's surface; but, at the same time, maintains every thing that lives upon it. Every living being requires the support of that mobile fluid. It affords nourishment to animals and plants; it not only supplies substances, but carries forces into organic beings; it is a real source of life to every living thing on our planet.

One of the most magnificent contrivances of the material world, is that which is exhibited in the innumerable changes undergone by the same substances, which, appearing in various forms, at one time constitute parts either of the atmosphere, or of the black soil—at another, the component parts of living plants and of animals.

We have acknowledged, as a general law, that the same elements may assume thousands of forms, and produce new combinations, though they cannot change their essential character: and that by means of the same substances, in various instances, nature attains entirely different ends. The substances which, in an organized form, adorn the earth, will ere long be decomposed. Their constituents, combined in a different manner, will soon assume a new shape, but will present themselves in the interval as component parts of the black soil and of the atmosphere. Thus the same substances at one time float in the atmosphere which envelopes the earth, and at another are component parts of plants and animals.

For these purposes, nature employs a small portion of matter only, as compared with the large mass of the earth. Though apparently so very liberal in maintaining life, she is at the same time economical in applying the material means by which that object is effected. The number of

animals and plants, which may at any time have existed on the earth, could scarcely be greater than it is now, because there would be a want of the materials requisite for sustaining their existence. With the increase of the number of animals, that of plants must diminish, because the former are composed of parts of the latter. In the thin, black layer of soil, the constituents of animals and plants, and a little intermixture of the atmosphere, we have the whole store which exists on the earth, of the materials necessary for the existence and support of living, of organized beings.

Let us now consider the atmosphere in its connection with organized nature. Unknown in ancient times, it is at present acknowledged to be a main source of life to every living being upon the earth.

Accordingly we must bear in mind what the atmosphere is composed of; what influence it now exerts on the life of plants and animals; what influence is exercised by these in their turn upon the atmosphere; what its probable state has been in former times; and what influence it then exerted;—and, finally, we shall have to consider what causes actually exist, with power to modify the nature of the atmosphere; and to inquire what is likely to be its future state, so that we may form some idea of its influence on what will then be living.

The atmosphere, we know, is an invisible, very mobile veil of our planet, extended upwards to a great distance, and tending to occupy every space not occupied by other substances. Being kept in continual motion by general and special causes, it forms a uniform mixture of a few principal ingredients; but is, at the same time, the receptacle of all the volatile particles, of all the vapours from the earth's surface. The causes which produce its motion are among the most beautiful which investigation has observed in nature. Without that motion, every disturbance of the composition of the atmosphere would necessarily be pernicious to the life of plants and animals; every organized substance would become surrounded by an atmosphere of its own, expending what is useful, and leaving what is useless, so as soon to be deprived of everything not

belonging to that by which it is immediately encompassed. Were the atmosphere a motionless mass—from which something is taken, and into which something is discharged, and in a different way by every organized being—then all things now alive on the earth's surface would in a few days be destroyed. It is, therefore, a wise and inestimably excellent contrivance, that thousands of causes are at work, to keep the atmosphere in uninterrupted motion. What may be pernicious to one organism, is indispensable to another;—what is left from the abundance of one, is usefully applied by another;—what in one place is copiously produced, and might be detrimental, is rendered innoxious by being widely diffused through the ever-moving atmosphere.

I have purposely drawn attention, in the first place, to the continual motion maintained in the atmosphere, by the action of varying temperature and other causes; because in this lies the chief argument in favour of the opinion, that the atmosphere—however it may be composed, and whatsoever may be either discharged into it or taken from it—must be a uniform mixture; and that everywhere, over the whole earth's surface, and at every height, it must contain the same constituents. The direct consequence of this beautiful contrivance of nature is, that all the organized beings on the earth's surface, wherever they may dwell, are, as regards the atmosphere, exposed to the same influences.

The chief constituents of the atmosphere are four in number—oxygen, nitrogen, carbonic acid, and aqueous vapour. The proportions of the two latter vary with many circumstances, in a way which we can detect by observation—the way in which the proportions of the two former vary has hitherto escaped us. The received proportions of oxygen and nitrogen are, 21 of the former, and 79 of the latter, by volume—the carbonic acid averages nearly half a thousandth part—the quantity of watery vapour is very variable.

To these principal constituents of the atmosphere thousands of others are added. Volatile exhalations from the organized matter of the soil,—products of the volcanoes on the earth's surface, and of the artificial burning of fuel,—gaseous fluids

escaping from mines,—vapours of volatile solid substances,—hundreds of volatile oils from odoriferous plants,—putrid volatile products of animal and vegetable decomposition,—the muriatic acid arising from salt water in shallow lakes and lagoons,*—exhalations of men and animals,—an innumerable multitude of substances ascending in vapour from manufactures and chemical processes,—and finally, the volatile products of animal excrements ;—all these are sources of pollution to the atmosphere, which thereby undergoes innumerable alterations in its composition.

The accumulation of these multifarious substances in the atmosphere is prevented by one single cause, which is among the most remarkable we know ;—a cause, which is the same for the whole earth, which originates in the same source, and acts for the same purpose ;—a cause as sublime in its effects, as it is simple in its nature ;—a cause only to be brought into operation by the Supreme Wisdom, which can attain innumerable ends by one means. It is the rain which, in falling, carries with it everything that floats in the atmosphere, and which is not essential to its constitution ; which brings back to the earth, what came from the earth ; and which, whilst it thus purifies the atmosphere from noxious immixtures, carries the thousands of volatile substances into the soil, in which they have abundant opportunities of forming innoxious combinations with the substances which the soil contains.

The atmosphere, thus purified by means of rains from all heterogeneous mixtures, and kept in constant motion by currents of air, is a mixture of four substances. Let us shortly consider how we may accurately investigate them.

1° To determine the composition of the atmospheric air, it is necessary to ascertain accurately the amount of nitrogen and oxygen, its two chief constituents, and also that of the carbonic acid and aqueous vapour.

As to the former,—the determination of the amount of oxygen and nitrogen,—the first experiments for this purpose

* Mülder found free muriatic acid in the rain-water of Amsterdam, which he ascribes to the decomposition of the chloride of magnesium contained in the waters of the Lake of Haarlem by the action of the sun's rays.—*J.*

are comparatively recent; for it is not long since weights and measures began to be employed in the science of chemistry. Lavoisier was the first who used the balance, and he but rarely. When, in the latter part of last century, the kilogramme was introduced, it was noticed as a singular circumstance by the committee, assembled at Paris for the purpose of considering the subject, that the mechanician, Fortin, had made a balance, which sensibly indicated one milligramme. The whole science of measuring and weighing is scarcely sixty years old. The just determination of the composition of the atmosphere cannot, therefore, be older.

Besides some older experiments by Scheele, Priestley, Cavendish, and Horace Benedict de Saussure, those of Volta, de Marti, Spallanzani, Berger, Configliachi, Dalton, Humphry and Edmund Davy, Biot, Gay Lussac, von Humboldt, Brunner, Theodore de Saussure, Verver, and Dumas, have been mainly useful in determining the composition of the atmosphere.

At first this composition was thought to be variable. Instruments were invented to determine the amount of oxygen in the air. According as the proportion of oxygen was large, the air was thought better adapted for respiration. Hence these instruments were called *eudiometers*, that is, measures of the degree of the air's adaptation for that specific purpose.

The invariableness of the mixture was first stated in the year 1804, by von Humboldt and Gay Lussac, who, during the months of November and December, in dry as well as in moist or rainy weather, and during various states of the wind, collected the air of Paris, above the Seine, and subjected it to eudiometrical examination. In 29 experiments, made on 29 different days, the largest quantity of oxygen they found was 21.2, the smallest 20.9. The difference between these two numbers lies within the limits of the ordinary errors of experiment.

Since a constant composition, namely, 21 of oxygen to 79 of nitrogen, was thus assigned to the atmosphere by men of so high reputation as von Humboldt and Gay Lussac, it has scarcely ever been questioned. Their results have been confirmed by those of most succeeding experimenters.

Thirty years later, the air round and within Geneva was examined in an entirely different way by Theodore de Saussure. For this purpose he employed finely divided lead, which, diffused through water, he agitated with the air under examination—a method which was followed in London a few years ago, for manufacturing white lead.

By thus agitating air with moistened lead, de Saussure combined its oxygen with the metal, and thus nitrogen only remained. From his experiments made with air, collected over the Lake of Geneva, and at Chambeisy, it appears, that during very various winds and states of the weather, the minimum of oxygen was 20.98, and the maximum 21.15—the average of a great many experiments being 21.05.

The same results were obtained by Gay Lussac, who, on his ascent in a balloon, brought with him air from a height of 21,430 feet; by von Humboldt, who analysed air from the Antisana, a mountain of 16,640 feet high; by Gay Lussac and von Humboldt, with air from Mont Cenis, at a height of 6170 feet; and by Configliachi, from the Legnone, a mountain 8130 feet high. Finally, Dumas has recently found the same results confirmed, when air is passed over red-hot copper, and the nitrogen is collected.

Not only pure, but impure air also, has been found to give, after the foreign ingredients were separated and subtracted, 21 to 79 as the proportions of the two gases, in the remaining mixture of oxygen and nitrogen. For example, Configliachi examined the air collected over rice fields,—Seguin, Gay Lussac, and von Humboldt, that which was collected in a theatre at Paris, filled with people,—E. Davy, that from hospitals,—Theodore de Saussure, that from a bed-room in the morning. All these specimens of air showed no variation whatever in the amount of oxygen and nitrogen, provided the foreign mixtures were previously separated.

But, according to Levy, this composition is not invariable. He found, for instance, in the air of Guadaloupe, collected by Deville from different places, the following per centage of oxygen by weight:—

November	28, 1842,	22.68	Oxygen.
...	23,	22.85	...
...	29,	23.00	...
...	20,	23.03	...
...	27,	23.04	...
...	21,	23.05	...
...	23,	23.14	...

The air at Copenhagen gave, from the 17th of November to the 22d of December, 1841, 23 per cent. of oxygen by weight. At Elsineur, close to the sea, he found, in February, 1842, 23.037.

During a journey from Havre to Copenhagen, he collected air, which, on the 2d, 3d, and 4th of August, gave 22.6 of oxygen.

Levy ascribes this difference to oxygen given off by Infusoria, which are occasionally found in sea-water (see below). But it may be asked, if that difference ought not to be ascribed rather to error in his experiments?* It is safer, therefore, at present to consider the composition of the atmosphere to be constant in so far as regards the relative proportions of the oxygen and nitrogen.

Yet we ought not to conclude positively, that the proportion of oxygen and nitrogen never changes. All we are warranted to infer is, that the existing variation lies beyond the reach of observation; that the causes of disturbance are not greater than those by which the difference is made up; that in walled rooms the disturbed equilibrium is much too quickly restored by the draught of air, to admit of its being observed; that in open air the winds quickly supply whatever

* See Journal de Chemie et de Pharmacie, May, 1844, p. 212.—Morren, however, has lately, to a certain extent, confirmed the results of Levy. He found that air, collected on the immediate surface of large ponds of sea-water covering many sea-weeds, in the middle of a clear and very calm sunny day in April, contained 23 per cent. of its bulk of oxygen. This excess of oxygen he attributes to the rapid escape of bubbles of oxygen gas from the surface of the water, and of the green plants beneath it under the influence of the sun's rays. Of course, this gas will soon mix with the surrounding air, and at a very small distance from, or height above, the water, all sensible difference in the per centage of oxygen should disappear. See Annales de Chem. et de Phys., xii. p. 34.—*J.*

portion of the oxygen may, by various circumstances, be abstracted.

The quantity of this oxygen is indeed astonishing. If we assume the height of the atmosphere to be a geographical mile, that is, 22,843 feet;—if we bear in mind, that the radius of the earth is 860 of these miles, then the bulk of the air amounts to 9,307,500 cubic miles, that is, a cube of which the side is 210 miles; so that, there being 21 per cent. of oxygen, the earth is surrounded by a quantity of this gas, equal to a cube of which the side is 125 miles;*—an astonishing quantity, indeed, in which small disturbing causes must necessarily escape our observation. (Poggendorff, in Handwörtebuch, i., S. 562.)

2° The amount of carbonic acid in the air is pretty constant. It has been determined in various ways. Dalton agitated a known volume of air with lime-water, and weighed the quantity of carbonate of lime he got. Thenard employed baryta-water for the same purpose. Theodore de Saussure took a small bottle containing baryta-water, and suspended it in a balloon filled with air. Brunner transmitted air, by means of an aspirator, through sulphuric acid, moistened lime, and again through sulphuric acid, and weighed the two latter substances, contained in a proper apparatus.

In 1827 and 1829, de Saussure made 225 experiments, to determine the proportion of carbonic acid in the air. He found, by 104 experiments with the air of Chambeisy, a small village near Geneva, that the quantity of carbonic acid in 10,000 parts of air was, on the average, 4.15, the minimum being 3.15, the maximum 5.74. This difference is too great to be ascribed to errors of observation. De Saussure further found, that during the day the air contained less carbonic acid than during the night. He found, during the day, an average of 3.38, during the night, of 4.32; the maximum during the day was 5.4, during the night, 5.74. With slight winds at mid-day he found a smaller quantity of carbonic acid than when the wind was violent;—in the former case, 3.76,

* Of the mile here spoken of there are 16 to a degree, and it is equal to 4½ English miles. Of the *common* German mile there are 15 to a degree.—*J.*

in the latter, 3.98. The quantity of carbonic acid was diminished less by violent showers, than by continued gentle rains. The quantity was greater over cultivated grounds, than over the Lake of Geneva; at Chambeisy, he found 4.60, when the air above the Lake of Geneva gave him 4.39. In 30 observations, which he made simultaneously at Chambeisy, and in a street of Geneva, he found the proportion in the air in the neighbourhood of Geneva, 4.37; in that of the town itself, 4.68, showing a larger quantity of carbonic acid in the latter place. Finally, he found that on mountains the air contained somewhat more carbonic acid than in the lower regions of the atmosphere; the difference, however, was very small.

The same experiments were repeated by Verver, after the method of Brunner, and his results confirmed those of de Saussure.*

3° We must here advert to the quantity of ammonia in the atmosphere, which is considered by Liebig† of such great importance to the growth of plants. It frequently happens, that traces of ammonia are found in rain-water; but its quantity is so very small, that Liebig himself could obtain only a trace from many hundreds of pounds of rain-water. In another work (Scheikundige Onderzoekingen, Deel II., p. 78), I have shown it to be impossible that plants should obtain their nitrogen from that source—that the quantity of ammonia in the atmosphere is exceedingly small—and that, in fact, it should not take any higher rank as regards organic nature, than the many other substances accidentally mixed in minute quantity with the atmosphere, and which are really innu-

* Verver's results, obtained at Groningen, give 4.2 parts in 10,000, his maximum being 5.1, and his minimum 3.5. Since these were published, an elaborate series of observations has been published by Boussingault. The mean for nine months, according to his observations made in Paris, was 4 parts in 10,000, the minimum being 2.2, and the maximum 6.7. A series of 16 experiments, made on the same successive days in September and October, 1843, and at the same hours by Boussingault in Paris, and Levy at Andilly, near Montmorency, gave for the carbonic acid in the air of the city 3.19, and in that of the country, 2.989. This is in accordance with the result of de Saussure. Ann. de Chem. et de Phys., x. 66, 462, and 472.—*J.*

† Organic Chemistry applied to Agriculture.

merable. I shall recur to this point, however, in treating of arable soil. For the present, it may be enough to remark, that the atmosphere contains a quantity of ammonia which as yet it has not been found possible to weigh; and which, to organized nature, is but of secondary importance.

4° The quantity of water in the atmosphere varies considerably, at different times and in different places. It is, besides, dependent on the temperature of the air, and of the water evaporating from the earth's surface. The air being in contact in one place with large collections of water, which are continually evaporating, and in another with dry, arid ground, this variation must be considerable. The continual rising of currents of air, causes the vapours which are diffused through the atmosphere to form clouds, that is, utricular vapours, which float in the atmosphere at a height of from 5,000 to 20,000 feet, according to the latitude of the place. By the ascent of these, the lower parts of the atmosphere are deprived of their aqueous vapour, the quantity of which is thus dependent on the source and temperature of the evaporating fluid, on the temperature of the air, the velocity of the wind, and many other causes. Atmospheric air is never quite dry, as it is never quite free from carbonic acid. To some substances this moisture obstinately adheres; others absorb it gradually and become liquid; while others again are changed in their nature through its influence. For instance, the rusting of metals is a combined effect of the moisture of the atmosphere, of its carbonic acid, and of its oxygen. In a word, an acquaintance with the quantity of aqueous vapour in the atmosphere is of the greatest importance to a right knowledge of its peculiar properties.

The proportion of aqueous vapour has been determined by Verver for the Netherlands. In 1000 volumes of air he found the minimum 5.8; the maximum 10.18; the former on the 24th of August, at ten o'clock A.M.; the latter on the 4th of May, at half-past eleven A.M. The average of 50 observations, during May, August, and September, was 8.47. From an early hour in the morning to 10 o'clock A.M., it was 7.97—from 10 to 2 o'clock P.M., 8.58—and from 2 o'clock till the evening, 8.85. (Bulletin, 1840, p. 191.)

5° Finally, Boussingault, Verver, and others, have shown the presence in the atmosphere of other substances, which contain hydrogen and carbon. Boussingault and Verver passed atmospheric air, *freed from carbonic acid*, over red-hot copper, and obtained small quantities of water and carbonic acid. By means of the oxygen of the air, the hydrogen and the carbon—no matter in what state they existed in it—would be changed into water and carbonic acid, while passing together over red-hot copper.

We cannot determine in what state this hydrogen and carbon are contained in the atmosphere; they may be so, in the form of hydrogen gas, carburetted hydrogen, and carbonic oxide, or possibly in that of volatile organic substances. As to this point, nothing has yet been ascertained, nor can it be determined by such experiments as these. It is certain, however, that, before the constituents of organized bodies are reduced to their most intimate combinations, they can assume a great many intermediate states—supplying the atmosphere with either solid, liquid, or gaseous products. Thus, in every kind of putrefaction, peculiar volatile substances are diffused through the air, which may contain the four organic elements combined in various ways. Further, in a great many diseases—such, for example, as cause eruptions on the skin—volatile compounds escape from the patients, and are diffused through the atmosphere.* Many substances, also, which, both at ordinary and at more elevated temperatures, are regarded as fixed and not volatile, are constantly emitting particles in a state of vapour, and diffusing them through the atmosphere—such, for instance, are potash, soda, and even iron, when smelted in blast furnaces. Thus, the atmosphere must contain not only substances consisting of carbon, hydrogen, nitrogen, and oxygen, but a great many others

* See on this subject the elaborate treatise of Dr J. Van Geuns, Natuur-en Geneeskundige Beschouwingen van Moerassen en Moeraasziekten. Amsterdam, 1839. (Physical and Medical Considerations on Marshes and Marsh Diseases. Amsterdam, 1839.) Mülder's Verhandeling over de Wateren en de Lucht van Amsterdam (Treatise on the Waters and the Air of Amsterdam), p. 163, may also be consulted on this subject.

besides, which it would really be of importance to investigate, but on which it is unnecessary for our present purpose to dwell.

We are, therefore, entitled to state, as a general result of this brief enumeration of the component parts of the atmosphere, that besides a countless number of accidental ingredients, which are continually carried down again to the earth by the rain, the chief constituents of the atmosphere are a mixture—nearly constant, as far as we are able to observe—of 21 parts of oxygen and 79 of nitrogen by volume, a variable proportion of aqueous vapour, and a quantity of carbonic acid, which amounts on an average to something less than half a thousandth part.

Two great causes of disturbance are continually at work to diminish the quantity of oxygen in the atmosphere, namely, the respiration of animals, and combustion. By these processes, vast quantities of oxygen are consumed, and combined with carbon into carbonic acid. We shall afterwards inquire, how far these causes may tend to change the composition of the atmosphere; at present we only remark, that those two disturbing causes are opposed by a third, which, if the equilibrium be disturbed, may restore it again, namely, the decomposition of the carbonic acid by plants, and the separation of oxygen by their green parts. This decomposition is one of great importance. While the larger animals, by their respiration, continually extract oxygen from the atmosphere, and give off carbonic acid, plants, on the other hand, absorb carbonic acid and give off oxygen;—this evolution of oxygen being their action during the transformation of the nutritive substances which they have absorbed, and among which carbonic acid is one of the most important—into other compounds, either poor in, or altogether destitute of oxygen. In relation to the atmosphere, therefore, the larger animals and plants are directly opposed to each other, and we shall afterwards treat of their several functions in this respect.

To this generally acting cause, tending to restore the equilibrium, previously disturbed by respiration and combustion, a second remains to be added, which is of no less importance,

though of less extensive influence, than the green parts of plants. I refer to the very remarkable observation made by Morren,* that not only plants, but also some kinds of animals, very simple in their structure, give off oxygen, when exposed to the rays of the sun. After a great many analyses of the air contained in different kinds of water, from wells, from stagnant pools, and from marshes, it appeared to him, that such of the latter as contained a greenish, minutely divided substance, gave off a considerable portion of oxygen—so that, according to his calculation, from a bulk of water of 8000 cubic feet, in favourable circumstances, 128 cubic feet of oxygen were given off into the atmosphere in a single day. This production of oxygen was dependent on the sunshine, and reached its maximum on a clear summer's day, about four or five o'clock in the afternoon. The quantity of gas, during its strongest evolution, was considerably diminished by the interposition of a piece of black cloth. He found the largest proportion of oxygen in 100 parts of air from the water to be 61; the smallest 16 to 17.† The green substance, to which this disengagement of oxygen was to be ascribed, he found, when observed through the microscope, to consist, for the most part, of the *Enchelis monadina virescens sulesphoenea* of Bory de St. Vincent, occasionally mixed with the *Enchelis pulvisculus viridis* of Müller, the *Monas bicolor* of Ehrenberg, &c., which are small monads—animalcules, therefore, performing the same functions which are usually performed by plants.

From the smaller proportion of oxygen obtained during the night than during the day, a deviation which always depended on the quantity of these green animalcules in the water, Morren drew the conclusion, that they decompose the carbonic acid contained in the water, retaining and living

* Annales de Chemie et de Physique, Avril, 1841, and Biblioth. Univers. Novemb. 1841, p. 386.

† Morren states the very interesting fact, that when, in June, 1835, the air in the waters of the river Marne, a slow-flowing river, contained only 18 per cent. of oxygen, great numbers of particular kinds of fish perished. How beautifully does this prove the wise purpose for which the air, in our rivers and seas, has been made to contain so large a proportion of oxygen!—*J.*

on the carbon in the same manner as plants do; whence it is to be presumed that their chemical constitution may nearly resemble that of plants.

Morren obtained the same result from other microscopical animalcules, which were not green, but red; the proportion, however, which they gave off, reached a maximum of 47 per cent. only. These animalcules were the *Tracholomonas volvocina* of Ehrenberg, of a beautiful red purple colour. The green colour of the former, therefore, has no relation whatsoever to the quantity of oxygen evolved. The difference between the quantities of oxygen, produced by both kinds of animalcules, may be ascribed to accidental causes.

Wöhler has made the same observation. In the salt-water springs of Kur-Hesse, a green mucilaginous matter is formed during the summer's heat, in which great numbers of air-bubbles appear. These bubbles contain 51 per cent. of oxygen, and 49 of nitrogen. The green matter consists almost entirely of species of Navicula and Gallionella, mixed with fibres of Confervæ—in a word, for the most part, of Infusoria.*

In this, therefore, a new source of purification to the atmosphere has been discovered. Not only do plants decompose the carbonic acid, but the countless multitudes of Infusoria, which are to be found in stagnant waters, act as auxiliaries to the plants, in decomposing carbonic acid and extricating its oxygen.†

It is almost certain, that the atmosphere has always consisted of nearly the same constituents as at present. I do not here refer to what it might have been in another order of

* Annalen der Chemie und Pharmacie, 1842.

† Morren has more lately found that the air in *sea* water, which, when the sky is obscure, contains 33 per cent. of oxygen, contains more after some hours of bright sunshine, and varies between 31 and 39 per cent. It is least in the morning and in cloudy weather, and greatest after mid-day, and in prolonged bright weather. The whole sea, therefore, may be considered as a constant purifier of the air, removing its carbonic acid and renewing its oxygen. It does not appear, from Morren's researches, that *visible* Infusorial animals are necessary to this action of sea-water, as, in the water he examined, the microscope showed the presence of very few Infusoria. Is the effect produced by animals too minute even for the microscope?—*J.*

things; I allude only to the state in which it has existed since the last great geological revolution, and especially since the dispersion of man over the earth's surface. Much too short a period has intervened, since eudiometrical experiments—determinations of the relative proportions, that is, of oxygen and nitrogen—were first made, to admit of any positive conclusion being drawn; but there are other grounds, which seem to warrant the inference, that the proportion of the oxygen to the nitrogen in the atmosphere, as now known, is as old as the existing state of things, or, at least, may at first have but slightly differed from what we find it now;—it being probable, also, that previous to that time, the atmosphere was entirely different from what it is now.

It is not to be denied, that the carbonic acid, which is discharged into the air by animals and by combustion, is decomposed by plants. They decompose the amount supplied to them from these sources, and disengage its oxygen. They cannot decompose more. Thus vegetation, or the number of plants, depends on the quantity of carbonic acid in the air, and conversely upon the number of plants depends the quantity of oxygen which is liberated from the decomposed carbonic acid;—and thus the life of animals depends on the number of plants.

There are some plants which live entirely on what they receive from the atmosphere, without drawing any food from the soil, except some inorganic salts and bases. To these belong, among others, the lichens and mosses, with which the bare rocks are covered, and which grow in inaccessible places, where no change has ever been effected by the hand of man, and no natural deposit has ever been made. To these further belong many phanerogamic plants, the so-called fatty plants (*plantes grasses*), a great many Cacti, Euphorbias, Sempervivum, &c., and a great many of the false parasitical plants, which are fixed to trunks and branches of trees by means of their own roots, and do not draw any of their food from them. (Miquel.)*

It cannot be ascertained, how the germs of the lichens and

* Bulletin, 1838, p. 86. Pl. I. fig. B.

mosses have first been produced, or originally brought to their present place. It is sufficient for us that they do exist, and that they grow by means of the atmosphere.

A vegetation of this kind must necessarily have preceded the present one; for there was a time when no soil existed, and its organic parts, together with those of animals and plants, were constituents of the atmosphere.

The first plants which grew upon the earth, but no longer exist in a living form—though they have been accurately determined by geology from their remains—could have found no humus, but must have derived their organic constituents from the atmosphere. Among them are found gigantic productions, which so resemble the existing vegetation in structure, that it may be assumed as certain, that the function of nourishment has never been subjected to other laws than those which we recognise in the existing vegetation. At that time, in the primitive world, the naked rocks must have been covered with gigantic Equisetaceæ, Lycopodiaceæ, arborescent ferns, and pines.*

Plants, which now live on the atmosphere, require carbonic acid, water, and nitrogen; the last of which, by the decomposition of water, gives rise to ammonia, under conditions of which we shall afterwards treat. (See *Arable Soil.*) In this manner they obtain carbonic acid, water, and ammonia, in which they find all their nourishment; the atmosphere can-

* Bronn, Lethæa Geognostica, 1 Bd. Brogniart, Prodrome d'une Histoire des Vegetaux Fossiles. Paris, 1828.

It may reasonably, I think, be doubted whether observed facts in geology bear out this opinion of Mülder in regard to the entire absence of a vegetable soil in those remote times when the trees referred to flourished on the earth's surface. The dirt-bed of the Isle of Portland, and other localities, which lies between the marine deposits of the Oolite and the fresh-water strata of the Wealden, is an ancient soil in which many trees grew; and the clays on which nearly all our beds of coal, without exception, rest, and in which so many roots are found, is no doubt the soil in which the vegetation of that epoch was fixed. Trees are known now, both in our own and in warmer and drier climates, to grow occasionally on naked rocks; but woods and forests grow only where a soil exists. In the absence of any facts to the contrary, therefore, it is safer to believe that, in the early geological epochs, when terrestrial vegetation prevailed, vegetable soils also were gradually produced.—*J.*

not give them more; and as they live on nothing but carbonic acid, water, and nitrogen, in the form of ammonia, they must be able to prepare from these substances their several peculiar constituents.

If we suppose such plants as now grow upon bare rocks, to be planted in a stony soil within an enclosed space, and surrounded by an atmosphere of carbonic acid, aqueous vapour, and nitrogen, from which last ammonia may be produced by the decomposition of the water—then these plants will decompose the carbonic acid, and give off the oxygen; and from the ammonia, the carbon, and part of the carbonic acid left behind, as well as the water, several vegetable substances will be produced, which will adhere to the stony ground. The further the decomposition of carbonic acid and the condensation of nitrogen proceed, the better do the plants grow—the greater is the amount of the four organic elements which they fix to the stony ground; and the greater also the amount of oxygen which is mixed with the surrounding nitrogen, carbonic acid, and aqueous vapour.

If the plants, after the seed is matured, die within this enclosed space, then they putrefy, and organic humus-like substances are left behind. The decomposition of these substances proceeds still farther, and the products are carbonic acid, which is diffused through the air, and ammonia, which remains intimately combined with the humic substances of the soil. In these decaying substances, the seed sprouts and grows to a small plant; the carbonic acid from the air, and the ammonia formed from nitrogen and aqueous vapour, are decomposed by the young plant; the latter thereby is advanced in its growth, gives off oxygen, and produces new organic substances, which again form constituents of plants. These plants putrefy in their turn, and so this rotation is continually going on. The production of plants cannot exceed the supply of the substances on which they live; they can only rise to a height proportioned to the quantities of food afforded to them, which existed originally in the air in the state of gas. The nitrogen, which was in the enclosed space, along with carbonic acid and aqueous vapour, thus becomes mixed with

oxygen on the first decomposition of the carbonic acid by the plants; and this process is continued, till there is no more carbonic acid to be decomposed. Then the oxygen attains a maximum. When the dead plants decompose, their carbon at the same time takes up oxygen, and thus the quantity of the latter again falls towards a minimum, which is attained when putrefaction is completed, and young plants rise from the germinating seed. In such a limited space, the largest quantity of oxygen, and the smallest of carbonic acid and nitrogen, would exist when the plants had attained the period of most luxuriant growth; on the contrary, the smallest quantity of oxygen, and the largest of carbonic acid and nitrogen, would exist when the dead plants had reached the highest degree of putrefaction.

If we suppose that in the enclosed space, in which the stony ground is already covered with a layer of humic substances, and which contains ammonia and oxygen in the state of gas already mixed with the nitrogen, aqueous vapour, and carbonic acid—if we suppose that in this space the seeds of other plants are present, these will rise and attain a luxuriant growth, and will add to the condensation of carbon, hydrogen, and nitrogen from the surrounding gases, and to the disengagement of oxygen into the air.

Suppose, now, that at this point we enclose certain animals along with the plants, in the same limited space in which the latter have already mixed the nitrogen with oxygen, then the former will inhale the oxygen, and will substitute for it nearly an equal bulk of carbonic acid. The amount of carbonic acid in the enclosed space being thus increased, is again given to the plants for decomposition, which thereby grow more luxuriantly, and restore again a large quantity of oxygen. If these animals eat of the plants thus inclosed with them, a portion of the latter will be deprived of the power to decompose carbonic acid: but these animals soon give off their excrements, which putrefy, and produce carbonic acid and ammonia from the vegetable nourishment carried through the animal body. These new products are again offered as nourishment to the plants, which thereby grow and may again serve as food for other animals.

Finally, if we kindle a fire in the enclosed space after the oxygen is introduced, then the carbon of the burning organic substance will be changed into carbonic acid by the combustion, and in this way also food will be prepared for the plants.

If the supposition above made be applied to the whole atmosphere, all the operations described remain the same. At the creation of the most ancient order of things, there might, or might not be, oxygen in the atmosphere. If there were carbonic acid, nitrogen, and aqueous vapour, then, at the very first traces of this peculiar vegetation, of which so many indications remain, the plants must necessarily have absorbed carbonic acid and ammonia—formed from nitrogen and aqueous vapour—and so oxygen must have been diffused through the atmosphere. With the increase of vegetation, the carbonic acid and the nitrogen would gradually lessen in the atmosphere. The quantity of both would fall towards a minimum, while that of the oxygen would rise towards a maximum—the constituents of the primitive atmosphere being more and more condensed into solid substances on the rocky earth.

Plants may preserve their existence, without the presence of either animals or combustion. By the putrefaction which one part of them undergoes, carbonic acid and ammonia are supplied to the other part. Except the Infusoria, all animals must have begun to live after the existence of plants, for without plants no animals could live upon the earth. The black layer of soil must have come into existence after the plants, for it can be produced by plants and animals only. Thus the substance of the organic parts of animals and plants, and of the black layer of soil, were formerly component parts of the atmosphere.

Animals must have vegetable food. As soon, therefore, as animals arose on the earth, the quantity of carbonic acid in the atmosphere, and that of ammonia in the black layer of soil, began to be increased by their respiration ; and so the food for plants became more abundant. Thus vegetation must have been supported and promoted by the continual increase

of animals on the earth ; and the food supplied to plants from the atmosphere will still go on increasing, with the increasing numbers of mankind.

At the beginning of the present condition of things, also, a very remarkable change must have been produced in the atmosphere, by the formation of the black layer of soil. The first plants, which lived upon and were nourished by carbonic acid and ammonia, either derived or prepared from the atmosphere, did not restore to the atmosphere on their decay all they received from it, but left on the earth's surface a black solid substance. As that layer increased, the atmosphere must necessarily have been deprived of the elements of carbonic acid—and of ammonia, either condensed or formed from the atmosphere by the decayed plants. And in proportion as this layer of humus increased (as we see it at present doing on our moors and mosses), the atmosphere would become poorer and poorer in carbonic acid and nitrogen.

That the production of a new vegetation upon arid tracts of land is now going on so slowly, is to be ascribed to the reduction of the quantity of carbonic acid to a minimum by the great number of plants which have existed. Every new vegetation fixes carbon to the ground. If drawn from the atmosphere exclusively, this carbon does not easily return, but is chiefly applied to the support of the plants which grow on the spot where the layer of humus has been deposited.

After the creation, and especially after the dispersion of the human race, a new source of transformation of the elements came into existence, in addition to what animals were already contributing to the support of vegetation. The fires employed for warmth, for cooking, &c., provided new nourishment, through which, places hitherto bare might become covered with plants, and existing vegetables might increase in growth. The coal, for instance, which lies concealed under the earth's surface, being changed into carbonic acid by combining with the oxygen of the air, continually supplies to plants a new portion of nourishment. The more coal is consumed, the more new vegetable products (viz., cellulose and other indifferent substances not containing nitrogen) may be produced.

From the nature of these reactions, it follows, that the black layer of soil is a product of the decomposition of animals and vegetables, and could not have existed before these; that the plants which existed before its formation could have no other source of food but the atmosphere;—that this food must necessarily have been carbonic acid and ammonia;—that, by the increase of plants, and of the black layer of soil, the composition of the atmosphere must have been changed, the proportion of carbonic acid and nitrogen being diminished, while oxygen took the place of the former;—that during this time the proportion of oxygen in the atmosphere must therefore have been always increasing;—that a great quantity of carbon and nitrogen, being condensed on the earth's surface, having passed into plants, into the state of humus, and into every kind of organic substance, the proportion of carbonic acid present in the atmosphere must have become very minute, and the increase and extension of plants over tracts of land, not yet cultivated, must have been thereby materially obstructed;—that then, not only the extension of vegetation had attained its highest point, but that without other and peculiar causes, by which carbonic acid was again returned to the atmosphere, it could not have been maintained at that highest point;—that, by the animals which came after the plants, the change in the constituents of the atmosphere has been considerably increased, a larger portion of carbonic acid and nitrogen being separated from the earth's surface, and brought into a state fit for being moved and transported over the earth;—that animals, by supplying new food to plants, namely, carbonic acid and ammonia, have again considerably supported vegetation;—and finally, that by the increase of the number of mankind, by their respiration, by the putrefaction of their dead bodies, and above all, by their fires, this effect has been again powerfully promoted.

Has the atmosphere, since the appearance of man on the earth, preserved the same composition as it had before? and will it at all times retain the same composition—the number of mankind being continually increasing, and that of forests diminishing?

It is not to be denied, that the quantity of carbonic acid must have become greater, and that of oxygen less, with the increase in the numbers of men, who respire and make fires, and whose dead bodies putrefy ;—but, on the other hand, a great many animals, on the increase of mankind, have been expelled from the earth's surface. By the fires, however, which man has kindled, the quantity of carbonic acid has undoubtedly been increased, and that of oxygen diminished; but it is difficult to decide with certainty whether that increase in the carbonic acid would have ever become perceptible, even though the very first human beings had been able to make eudiometrical experiments. It is, however, probable, that in any given bulk of atmospheric air, they would have found a little more oxygen, and somewhat less carbonic acid, than in the present day, provided the method of investigation had been sufficiently accurate.

It is a consequence equally undeniable, that either the atmosphere will at last become infected by man, or that famine will arise on the earth. By the continual increase of man on the earth, the number of forests has been diminished. Man expels and destroys animals and plants, which previously lived undisturbed. It is principally by the large forests that the great quantity of carbonic acid, resulting from combustion and respiration, must be decomposed. There must necessarily be a proportion between the number of plants, and that of man and animals on the earth. The former must restore what the latter have taken from the atmosphere ;—the one must decompose what the other has imparted to the atmosphere. Wherever the equilibrium between the number of plants and animals is disturbed,—that is, when mankind increase and plants diminish,—then there will at last be no longer a sufficient quantity of carbonic acid decomposed, and the proportion between the oxygen and nitrogen, which we now assume to be invariable, will be altered.

It is true that a large portion of the earth, susceptible of cultivation, still remains uninhabited by man. But if, in imagination, we transfer ourselves into futurity,—if we suppose the woods destroyed, the earth covered with edible plants

which reach but to a small height in the atmosphere,—then we have in imagination reached a limit to the invariableness of the existing composition of the atmosphere, and at the same time to the existence of man upon our planet. The disappearance of the falls of Niagara and that of the human race belong to periods, which, it may be, are still far distant, but which, notwithstanding, will certainly arrive, if nothing meanwhile interpose.

When will that period arrive? This is a question to which we may give an approximate answer. According to the experiments of Lavoisier and Davy, a man consumes 26.04 Paris cubic feet of oxygen in 24 hours; that is, 9,505 cubic feet a year. Let us suppose the number of men on the earth 1,000 millions, then these consume 9,505,000,000,000 cubic feet of oxygen every year, that is, nearly 8-10ths of a cubic geographical mile. The whole amount of oxygen, by which the earth is surrounded, is 1,953,570 cubic geographical miles.* So that, if the number of mankind on the earth were always 1000 millions, they would require 2,451,000 years to take away all the oxygen from the atmosphere. If, from the present moment, plants were to cease decomposing carbonic acid, all the oxygen of the atmosphere would be exhausted after 2½ millions of years.

By the operation of this cause, therefore, the human race will at some time be destroyed, if it should not happen to be so previously from other causes.

Whence has originated that admirable uniformity in the composition of the atmosphere, which has been observed wherever and whenever it has been investigated? First, we must not conceal, that our eudiometrical methods are not among the most accurate; so that slight differences in the composition of the air may easily escape notice. It must have been owing to an error in the mode of experimenting, for instance, that after separating the carbonic acid from the air in the

* For this calculation of Poggendorff, the height of the atmosphere has been taken equal to one geographical mile, or 22,843 feet; the radius of the earth equal to 860 geographical miles, and thus the bulk of air, consisting of 21 of oxygen, and 79 of nitrogen=9,307,500 cubic geographical miles. (See *ante*, p. 102—note.)

pit of a theatre, where many people were breathing, the proportion of oxygen in the remainder was found the same as in the air outside of the building (Gay Lussac and von Humboldt). For, whence had the carbonic acid come, which is found in such air in so large a proportion? Whence could it be derived except from the oxygen consumed? This cannot be restored immediately by the opening of doors, &c.—since we should expect, that by the same cause the carbonic acid also ought to have been partially removed, though it be heavier. In such air, however, a great deal of carbonic acid was found, but no difference in the proportion of oxygen.

With the exception of these smaller errors of observation, the composition of the atmosphere is now everywhere constant, or nearly so.

The heavy rains in the first place carry to the earth many of the less important vapours. These vapours penetrate into it, either to be decomposed by plants, or to be converted into chemical compounds, in the substances of the earth's crust. Among the latter are the sulphuretted hydrogen given off by putrefaction, and many other substances, which combine with the metals of the salt-bases in the earth, and are gradually changed into salts by the influence of the oxygen of the air, which is present everywhere. In this manner carbonic acid, and the traces of ammonia, which exist in the air, are also conveyed to the small radicles of plants. And in like manner, after having remained in the ground for a longer period of time, those substances which are given off by the bodies of animals, &c., and are at first injurious to vegetation, must be decomposed and changed into new plants. (Ball, for instance,* having left the head of a Delphinus phocena to putrefy in a hothouse, found, after a time, a great many ferns, as well as other plants, in an unhealthy condition, withered, and discoloured; viz., Osmunda regalis, Adianthum capillus veneris, many species of Aspidium; also Rubus corylifolius, Oxalis acetosella, &c.)

But in that air-ocean itself, another, and a much more

* Biblioth. Univ., Nov. 1841, p. 412.

powerful, cause of its uniform composition exists, namely, the motion imparted to it by so many various causes, by which, in the tropics, hot strata of air rise, direct themselves to the North and South Poles, and thence extend themselves over the earth's surface to supply carbonic acid to plants for decomposition, and the oxygen, thence produced, to man, to animals, and to the support of combustion. It is owing to this effect of the winds, which depend on the temperature, and to which a great many other causes might be added, that an intimate mixture of the constituents of the air is maintained, and plants and animals alternately receive what is indispensable to each.

It deserves particular notice, that the two chief constituents of the atmosphere—oxygen and nitrogen—are not combined chemically, but merely mixed together. If they were chemically combined, the respiration of animals would be impossible, and the evolution of oxygen by plants would not restore the atmosphere to its proper state. The absorption, by the blood, of oxygen, which afterwards appears in the state of carbonic acid on the decomposition of the constituents of the blood, must be considered as a chief condition of the respiration of animals. This function would have been utterly impossible—the whole animal kingdom must have been entirely different from what it is at present, if the oxygen and nitrogen of the air had been chemically combined. During respiration, new compounds would in such a case have necessarily been formed in the animal organism itself, not only from the oxygen, but also from the nitrogen, in consequence of its being in the nascent state. The whole of the nitrogen of the atmosphere would then have been included in this action, whereas it is now almost wholly excluded.

Further, plants, which can now restore the disturbed equilibrium of the atmosphere by a simple separation of oxygen, would not be at all able to produce the necessary combination, were the atmosphere a chemical compound of oxygen and nitrogen. Where the combination was to take place, the quantity of nitrogen required might be deficient, and some other combination of oxygen and nitrogen might be produced;

in other words, a higher degree of oxidation. In short, if the oxygen and nitrogen were chemically combined, then organic nature would require to be very differently constituted; but as it is, the operation of the winds is sufficient to make the mixture an intimate and uniform one.

Finally, the absolute quantity of oxygen and nitrogen, which the atmosphere now contains, depends solely on the absence of substances from the earth, which either give to or take from this quantity, and upon the quantity originally appropriated to the formation of the atmosphere. This has not been determined after any chemical rule or natural law. But as the earth, once arid and rocky, and destitute of life, became covered with a peculiar vegetation—whose residue, coal, for instance, is astonishing—a vegetation possible only in the condition of the atmosphere as it then existed—so the greater part also of the present vegetation must be destroyed, when the constitution of the atmosphere undergoes the requisite change. Thus, every being which now has life depends for its existence on the presence of 21 per cent. of oxygen, and 79 per cent. of nitrogen in the atmosphere. Whenever this proportion is materially altered, every being, now alive on the earth, must die; and another series of plants and animals, perhaps a different race of rational beings also, will appear.

It is not known, how many such successive changes of organized beings have already happened on the earth's surface; but that they have happened is established as a certainty. Ehrenberg continues to make us acquainted with races of minute beings, which have powerfully contributed to the transformation of the earth's surface, and of which the influence on the condensation of the component parts of the former atmosphere must have been not less important, than that of the gigantic arborescent ferns, pines, and other plants of the primitive world, of which the remains are now buried under the earth's surface, but of which the organic parts once belonged to the atmosphere.

CHAPTER IV.

WATER, CONSIDERED IN ITS CONNEXION WITH ORGANIC NATURE.

While on the one side a mixture of two gases, both in a state of constant change, are the chief constituents of the existing atmosphere—on the other, a chemical combination of two volumes of hydrogen and one of oxygen, constitutes water, which performs a powerful part in organic nature, and greatly exceeds the atmospheric air in quantity. This difference between two substances, both equally indispensable to life, is of much importance. From the constituents of the atmosphere *not* being chemically combined, and from the elements of the water being so combined, many peculiarities of organic nature arise. The elements of the atmosphere, by their non-combination, afford plants the opportunity of restoring the quantity of oxygen which was changed into carbonic acid by respiration and combustion,—no other phenomenon taking place than a simple separation of oxygen.

But from the chemical combination of hydrogen and oxygen in water, a series of special consequences follows in the organic kingdom. It is a known fact that, when substances, chemically combined, are again decomposed, the action of other substances also, which are contained in the circle of action, is reciprocally awakened. Wherever, in the organic kingdom, water is decomposed—and this frequently happens—the decomposition reacts on the substance from which the influence proceeded, and produces important chemical transformations of all the substances included in the circle of action. This chemical action proceeds, as regards water, from two

elements, which are both chief constituents of organic bodies.

1° The first, and a very important effect of the water upon organized substances, is, that they are moistened by it. All the organized bodies of plants and animals need water to keep them alive. That water frequently plays a chemical part, forming hydrates with the organic compounds; but very often also it acts merely as a liquid, either to moisten, to dissolve, or to keep solid substances in suspension. We could not imagine vitality without water, or at least without some fluid, which would be a perfect substitute for water. The elements of such a fluid, therefore, must necessarily be chemically combined with each other.

2° This moistening water is indispensable, to keep the fleshy parts soft, to enable them to grow and be fed. The procreation of individuals is accompanied by the access of a large quantity of water; the germs of animals freely float in a liquid, that they may be able to move themselves easily, and by the ciliar motion at their surface, to produce from the water a continual renovation of substances at its surface. For the same reason, in young plants as well as in young animals, whose development and growth are rapid, the amount of water in the solid parts is also much greater. Regarded from this point of view, the presence of water in the atmosphere is a most beautiful contrivance, which has an intimate connexion with life. If the atmosphere were completely dry, the water of organic substances would quickly pass off by evaporation, many of them would be deprived of it, and the living being must necessarily die for want of water.

3° It is not less indispensable to life, as a dissolving and a suspending fluid. For it is only by the circulation of a fluid through the existing parts of an organic whole, that the support and nourishment of the whole organism can be effected; and many of its actions rest entirely upon this process. Without water, it would be impossible for the four organic elements to form the thousands of combinations which we observe; for by its intervention, the most heterogeneous substances are brought into mutual contact in the organism. Here the circulating fluid deposits some constituents, there it

takes up others, making them produce a new effect at a third place;—in short, the existence of water is inseparable from that of life.

4° The service performed by the water in plants and in animals is partly the same, and partly different. It is the same in so far as it forms hydrates of several compounds;—for instance, the hydrates of protein, which appear in plants and animals under different forms, though always in the state of hydrates, and those of mucilage, both of plants and animals. It is the same in so far as it keeps in suspension small particles, which are insoluble in water—such as the globules of chlorophyle in plants, and of the blood in animals; in so far as it carries dissolved substances through all parts of the organism—such as, the soapy matter of Scheele in plants, the extractive substances in animals, and in both a series of salts under various forms, and of diversified composition; and finally, in so far as it supplies to both animals and plants certain substances in a state of solution or minute division, which, being fitted to nourish, are indispensable to the existence of the organism.

5° The action of water differs, however, in plants and animals, chiefly as to the way in which it disappears again from the organic substances;—by which difference these two classes of beings are essentially distinguished from each other. In the greater part of animals, an aqueous fluid is circulated through the whole structure, and enters also into certain organs, by which a part of the substances either dissolved by that fluid, or suspended in it, are separated and expelled from the body—so that the latter gets rid of these substances. In plants this process is different. They are deficient in the organs which are exclusively destined to this service, and thus retain all the non-volatile substances which have ever entered into their composition. Exposing a large surface to the air, they lose aqueous vapours through their leaves, if the atmosphere can take up aqueous vapour—that is to say, if it be dry enough for that purpose, and if the hygroscopic power of the parts of the leaves be less than the power of the air to contain aqueous vapour. Though this be by no means always the case, it is, however, a condition which often arises;

so that plants, though not possessed of peculiar organs, fit for the expulsion of an aqueous fluid, yet lose, in many states of the atmosphere, almost pure water through their leaves. This function, therefore, is wholly different in plants and in animals. The latter, though they also lose water through their skin—both by exhalation through the pores, and by evaporation from the moist skin, covered with a thin epidermis—usually excrete, nevertheless, through peculiar organs (urine-excreting organs) a large portion of aqueous fluid. The leaves of plants, being possessed of stomata, and being besides in a moist state, lose water both through their stomata and over their whole surface, and impart it to the atmosphere. As this water can differ but little from pure water, much of the solid substances contained in the sap of plants must remain where the evaporation takes place —the growth of young leaves, which evaporate much, being thereby materially promoted. There is thus a growth, an increase of mass, in direct connexion with the evaporation of the aqueous fluid—that is, with the power of the atmosphere to absorb water. It is not to be denied, that by this evaporation of the water through the leaves and at the surface of plants, the renovation of the sap in the drying parts, and at the same time, the circulation of the sap in plants in general, is materially supported. The evaporated liquid must be restored, and besides the portion of the solid substances contained in the sap of plants, which this water leaves behind, the succeeding portion of liquid supplies a fresh quantity, which, in its turn, is left behind at the place of evaporation.

Another consequence of this evaporation and circulation is, that the ascension of new fluids through the whole plant is promoted, and so through its whole mass a new change of constituents must be produced.

6° Pure water is scarcely ever to be found at the earth's surface. Generally, it holds some saline substances in solution. These are found abundantly in nature, especially in sea-water. Without these very saline substances, animals and plants could not exist. They are as indispensable to life as the four

organic elements themselves. This connexion is undoubtedly not an accidental, but a necessary one. It places living nature in a peculiar relation to the so-called dead nature. If we imagine the organic parts of the serum of the blood separated from it, then there remains a saline solution, which, in many respects, approaches in composition to common water. Such coincidences are by no means accidental, neither is the necessity of common salt for animal life, and its abundance in the earth, accidental. Besides, not only in the serum of the blood, and in common water, but also in the aqueous fluid which circulates through plants, are contained the chlorides of calcium and magnesium, the carbonates of soda, lime, and magnesia, and sulphate of soda, and in the serum of the blood, potash salts, and phosphates also. The greater part of these salts, essential to the constitution of the serum of the blood, are found in common water, and also in the saps of those plants which are destined for the nourishment of man and animals—an arrangement which establishes an intimate connexion between the subdivisions of nature, which scientific writers commonly separate too much.

By these salts, undoubtedly, an important part is played in the whole organic kingdom. It is known that the greater part of them retard chemical changes among the elements of organic bodies. By common salt, and many others of them, for example, meat is preserved from corruption. Thus, the first purpose for which salts exist in the organic kingdom, is undoubtedly to limit, in a greater or less degree, the change of materials, to modify it here and there—which change would undoubtedly proceed much too rapidly in the animal body, consisting of parts very susceptible of change —if these salts were wanting. Some of them, for instance the alkaline carbonates, serve to dissolve the compounds of protein; others, for instance the phosphates of lime, supply supports for the soft parts (in grasses this purpose is served by silica), and form chemical compounds with many organic substances; at the same time, from these and from the sulphates is derived the phosphorus and sulphur by which, in certain combinations, the organic substances are ac-

companied. Finally, the oxide of iron, present in the ash of plants, must be dissolved in water before it can be taken up by plants, which convey it to animals, solely in order that, through the influence of the same de-oxidizing circumstances in the organism of animals, it may enter as an organic element into the colouring matter of the blood, in the same way as phosphorus and sulphur do into many protein compounds.

All the salts, soluble in water, which are not fixed in the animal body, or whose constituents are not combined there, are necessarily carried away in the urine. We cannot imagine any reason why they should be retained in the kidneys, since they occur dissolved in the serum, and are also soluble in urine, which is an aqueous liquid. These salts must, therefore, be continually, and to the same amount, supplied from without. Except common salt, they are sufficiently abundant either in animal or vegetable food, or in common water, to restore what has been lost. Man requires common salt, in addition to these, and knows, even in the most uncivilized state, how to appropriate it, and so to satisfy this want of his body.

7° The light in which water exhibits itself is peculiarly striking, when we consider, that this fluid is the medium in which a countless multitude of plants and animals live, find food, die, and putrefy; and that the substances they leave behind serve for the production, growth, and sustenance of new organised beings, in the same manner as the atmospheric air and the soil together do, for plants and animals which are said to live in the air.

More than two-thirds of the surface of our planet are covered with water. In that amazingly extended mass, multitudes of peculiar beings live. The solid part of the earth is besides intersected and diversified, in every direction, with rivers and other bodies of water, in each of which plants and animals live. Being concealed from the eye by the surface of the water, and less accessible than substances on the dry land, they are less captivating in appearance, and attract, in an inferior degree, the attention of the natural philosopher. This world, however, deserves to be accurately known. Who

would venture to determine, whether the number of organized beings, living in the water, or in the atmosphere, is the greater?

8° By the great mobility of organic substances dissolved in fluids, their displacement and their union are in the highest degree promoted. In infusions of vegetable and animal substances, small animalcules, which thence derive their generic name of *Infusoria*, are easily produced. Their existence, commonly, is of short duration, as they devour each other, and disappear, while their substance serves to produce new individuals and new forms, and is converted into infusorial plants, which, in their turn, disappear, and make room for others. In every kind of stagnant water, in marshes and ditches, wherever they are found on the earth's surface, similar metamorphoses of small organized beings occur. Their production is promoted by the stillness of the mass of water; hence they are not so frequently found either in rivers, or in more extended collections of water, or in inland seas. The innumerable multitudes of small organized beings in marshy waters, derive their birth and existence from organic substances present in those waters. The organized beings there produced vary with the nature of the water itself, the circumstances to which it is exposed, and the substances with which it is mixed. Previous to the existence of our present plants and animals, similar Infusoria existed in innumerable multitudes: perhaps they have contributed to condense the component parts of the former atmosphere.

9° There subsists an intimate mutual connexion between the atmosphere and a limited portion of water. Wherever and in whatever way a small quantity of water is prevented from escaping into the ground, if it be exposed to the atmosphere, such an accumulation of organic substances takes place, that the shallow body of water becomes at last wholly filled up. The distribution of seed causes plants to spring up within it, which—finding abundant food in the organic substances which have been produced from the constituents of the atmosphere, and deposited there, altered by infusorial animals and plants, putrefied, changed into humic acid, apocrenic acid, &c.,—grow

there luxuriantly, raise their leaves beyond the water, drink in carbonic acid from the atmosphere, retain the carbon, and restore the oxygen. Every shallow mass of water is thus gradually filled up with peaty soil. In ponds and ditches this happens every year, so that they require to be widened and deepened, otherwise they would soon disappear. (Wiegmann, Entstehung des Torfs.)

We therefore observe an intimate relation between the atmosphere and the water. All the particles from the atmosphere which are washed down by the rains, are taken up by the water into which the rains fall. The great variety of substances diffused through the atmosphere, being mixed with the water, are gradually decomposed in it, and at last substances are produced similar to those which appear in the soil. (See Chapter V.)

Hence, in every confined mass of water the same substances are present as in the soil, and consequently, the plants living there are surrounded by a diluted solution of inorganic and organic salts, which are more or less the same with those of the soil. The water of ditches is coloured by apocrenates, and from these is derived an abundant supply of organic food, to be taken up by the roots of plants, which in great numbers are floating in the water.

In the great ocean an immense number of plants grow. Besides the sea-weeds and other water-plants with which the shores are covered, the vast quantities of the Sargassum Columbi, which float on the sea like the weeds on the surface of our ditches, are for this reason remarkable. This plant feeds on the organic substances of the sea-water, of which substances the water contains so great a quantity, that it has always a yellowish colour, and leaves behind a coloured mass of salt after evaporation. In those large masses of water where gigantic animals live, where their excrements are diffused, and their dead bodies putrefy, an amazing quantity of organic substances is accumulated, and for the greater part dissolved, or diffused in a state of minute division.

It is certain, also, that by these water-plants, a relation between the water and the atmosphere is established. When

growing, all the green plants give off oxygen, which is diffused through the water, and, by its intervention, partly through the atmosphere.

By the continual evaporation of almost pure water from the ocean, by the anti-putrescent power of the salts in sea-water, and by the continual supply of organic substances, carried by the rivers into the ocean,—the quantity of organic substances in the soil must necessarily be diminished, and consequently the quantity of food for the organized beings in the ocean, and at the same time their very number, must be increased. Thus we observe a tendency to enlarge that multitude of living beings in the ocean.

We have seen, that oxygen is given off by plants in stagnant waters, as far as they possess green parts. From this fact, and from the property which the water possesses, of absorbing oxygen more easily than nitrogen, we are forced to conclude, that the proportion of oxygen in the air which is dissolved in water, is greater than in that of the atmosphere. This was first observed in the water of the Seine, by von Humboldt and Gay Lussac, and it has been ascertained by others, in reference to every kind of water, not containing an abundance of organic putrefying substances. Instead of 21 per cent., we find 28 to 32 per cent. of oxygen in this air, dissolved by water. Hence the fishes are supplied more readily with oxygen,—the water thus impregnated flowing along the ramifications of the blood-vessels in the gills, and the carbonic acid, which at the same time is given off, being dissolved by the water. This carbonic acid is a food for plants, and thus in the water almost the same succession of changes takes place as in the atmosphere, namely, that oxygen is supplied to animals by plants, and carbonic acid to plants by animals.

It is well known, that by the plants which live upon the earth's surface and in the atmosphere, those organic substances are prepared, of which the bodies of animals are composed —for though some animals are carnivorous, yet the animal food they eat obtained its first existence from vegetable food. Such a process, however, does not take place in all the animals which live in water. First, there is an infinite num-

ber of smaller animals,—most of the Infusoria, for instance, which owe their production, growth, and increase to organic substances, either diffused through the water or dissolved in it, as is the case with plants of the lowest orders, such as moulds. It appears, besides, that some aquatic animals, of larger size, possess other sources of nourishment than those from which the food of the larger land animals is derived. For we see that many of them, for a considerable time, live, increase, and grow, in a small enclosed quantity of river-water, provided only it be gradually renewed by fresh river-water. It may be that they can be satisfied with little food, but whence do they derive that small quantity? Whence, if not from substances similar to those on which plants subsist—from organic substances in a state either of minute division or of solution, of which a small portion is present in the river-water. A familiar example of this kind we have in the common leech.

On this point, therefore, considerable obscurity still involves the economy of those animals that live in the water, which science is as yet unable to clear up. And though, among these animals, there are some herbivorous and others carnivorous, it is more than probable that many, like plants, can change organic substances, when minutely divided, into food. Perhaps from these organic substances Infusoria are formed in the first instance; then the larger-sized animals devour these, and so are nourished in the same manner as land animals are, upon vegetable and animal food.

CHAPTER V.

RELATION OF THE SOIL TO ORGANIC NATURE.

From what has been already stated, it is obvious that the black matter of the soil, with which the earth is covered—to the depth, in many places, of several feet, in others of a few inches, but which is often also entirely wanting—is the production of plants and animals. In fact, we perceive the formation of substances, similar to those of which its chief constituents are made up, from the products of the decomposition of organized beings, and we do not see it formed in any other way. We are, therefore, sufficiently entitled to assume, that these substances, wherever they are present in the earth's crust, have always been produced by the condensation of substances from the atmosphere through the intervention of animals and plants. There are other considerations, also, which lead to the same conclusion. Thus where neither plants nor animals exist, this black soil is not to be found; and on the other hand, where plants and animals exist in abundance, its quantity is materially increased. It is thus augmented by the plants which grow upon our dry heaths, and which, in reality, contribute, in a considerable degree, to the elevation of the ground. The water-pools, also, of the Old Netherlands, which in former times were at some periods of the year 40 or 60 feet deep, and of which a great part of the lower districts of the country consisted, have been filled up, and changed into habitable ground, by means of other races of plants and their decomposed remains.

The black layer of soil, so far as it contains organic sub-

stances, in whatever part of the earth we suppose it to exist without the interference of art, has therefore been produced by substances which were condensed from, and at one time formed part of, the atmosphere. It constitutes an intermediate link between the atmosphere on the one hand, and plants and animals on the other. Were we to adopt the practice now generally followed, of calling water, carbonic acid, ammonia, oxygen, and nitrogen, *inorganic* substances—a practice, however, which I consider inconsistent with accuracy and propriety—then surely we could not attribute the formation of the black matter of the soil to anything but the so-called organic substances. Its elements are combined in the same way as cellular fibre, starch, gum, and sugar—as every other organic substance. From this point, undoubtedly, proceed the first and sustaining causes of the movements to which the molecules in plants and in animals are subjected. The change of constitution, which takes place in its elements, is unquestionably transferred to the plants, which require a larger or smaller portion of it to be supplied to their roots for their luxuriant growth; and the same molecular motion passes afterwards from plants to animals. The soil, therefore, is, as I have said, an intermediate substance between the atmosphere on the one hand, and plants and animals on the other, through which that peculiar circle of chemical action, usually called organic action, is kept up. Some plants, it is true, may grow without soil; but it is also true, that almost all existing plants *require* to be fixed in the soil for their vigorous growth; and though their growth may not be in proportion to the amount of organic substances in the soil, still, a certain quantity of them appears to be required for the growth of many plants,—a fact well known to every one at all acquainted with horticulture. Hence, undoubtedly, carbonate of ammonia alone is not an adequate food for plants in general, though it may be the only food of some, if in certain circumstances it be supplied to them by the soil. The continual decomposition of the substances in the soil is thus a principal cause of the molecules in plants being put in motion—a motion which is transferred by them to animals. Without this continual

decomposition of substances in the soil, many plants which now exist would disappear from the earth This continual decomposition, therefore, is a service performed by the black soil, which is altogether different from what is called the *supplying of food* to plants.

The earth, which at first was surrounded by a mere atmosphere, and had nothing but rocks and water—and not even these at the very beginning—on its surface; which was a dead and arid mass, covered with fogs, and studded with volcanoes and lofty rocks, has been exposed to a great number of alterations on its surface. Soon after the water had been condensed, the influence of air, light, and moisture made its rocks crumble down and decay, the winds dispersing their *debris*, the water carrying them away, &c., by which processes the angular parts of the earth's surface would necessarily become rounded. In this manner, the exterior crust of the earth has been covered with many pulverised or granular substances. These must be a mixture of the fragments of those rocks which were most elevated above the earth's surface, and therefore, of silica, of salts of lime, magnesia, soda, and potash, and of alumina, oxide of iron, and oxide of manganese, combined with the acids of the same salts—with carbonic acid, sulphuric acid, phosphoric acid, and chlorine. In different parts of the earth, this external, decayed, powdery substance must be different,—no sufficient cause in most cases existing to move it far from the place where it was first formed. From the heights, from the mountains, or rocks themselves, they must have been carried down to the lower districts in the neighbourhood; but there they must have remained, until carried forth elsewhere by powerful revolutions. Hence the difference of the inorganic substances on the earth's surface,—a difference dependent on the nature of the rocks, the decaying surface of which was crumbled down. This decay is still going on, and the surface of the globe, originally angular, has been gradually rounded; the crumbled rocks are still widely dispersed by winds and streams, and by them the depths and valleys of the earth's surface are filled up. The high mountains, covered with eternal snow and ice, will

follow at the last. After their bases have been worn down and undermined by the action of water, they, in their turn, being overthrown and transported into the lower parts of the atmosphere, will be subjected to the ordinary influences which tend to round the earth, and will be finally broken to pieces and levelled.

Of these decaying rocks, some are very well known, namely, those from which clay originated—that very generally diffused substance, which is so valuable for the growth of plants. This clay is produced from feldspar, albite, and porcelain spar.

Feldspar, ... $KO, SiO^3 + Al^2O^3, 3(SiO^3)$
Albite, ... $NaO, SiO^3 + Al^2O^3, 3(SiO^3)$
Porcelain spar, $NaO, SiO^3 + Al^2O^3, SiO^3 + 3(CaO)\ 2(SiO^3) + 2(Al^2O^3, SiO^3)$

From these silicates of potash, soda, lime, and alumina, while decaying—that is, while influenced by the action of water and carbonic acid—part of the silica, together with the potash or soda, is washed away by the rains, and silicate of alumina, free silica, as well as undecomposed feldspar, albite, or porcelain spar, mixed together as clay, in the state of a fine powder, are carried down to the rivers or valleys, by the rains or melted snows.

It is chiefly the feldspar, so generally diffused, which is of importance here. Together with silicate of alumina, quartz, mica, free silica, free alumina, a little chalk, and oxide of iron, &c., it may be considered as mainly constituting common clay—mixed, however, with a great many other substances, which are met with by the clay in its course, and while it is suspended in the water. The part of these rocks, which, on their crumbling down, becomes soluble in water, supplies the salts of the common river-water.

The inorganic constituents of the arable soil have an unlimited influence upon the organic kingdom. Animals obtain their inorganic constituents partly from the water they consume—by which they have been washed out and taken up from the decayed rocks,—and partly from plants, which again extract their inorganic constituents from the earth's crust.

Hence, we perceive an intimate connection between the organic kingdom, and the composition of the upper layers of the earth's surface.

We cannot here present a complete view of the nature of those substances; a few remarks, therefore, must suffice.

Everything on the earth's surface, which is exposed to the influence of air, water, light, and heat, loses its cohesion, and crumbles down more or less. This is what we call decay.

If the decaying rocks are destitute of what are more properly called metallic oxides, such as those of lead, copper, &c.; but, on the other hand, contain compounds of silica, alumina, and oxide of iron, mixed with salts of potash, lime, magnesia, &c., they then may favour vegetation. The growth of certain groups of plants may be promoted by such decayed minerals as contain what those groups require; the growth of other groups by the constituents of other rocks.

It is, therefore, of the highest importance to become acquainted with these decayed rocks, which exist almost everywhere on the earth's surface. Those pulverised substances are but seldom found on the spot where they originated. They are carried along with the water, floating down from elevated places. Hence, it is often very difficult to indicate their origin with accuracy; for this reason, also, they are generally mixtures of various decayed rocks.

It is clear that the products of decay must vary with the nature of the minerals from which they are derived. But when silicates, however composed, are acted upon by moist air and carbonic acid, the silica is separated, and carbonates are produced.

This is the case, not only with the generally diffused feldspar above mentioned, but also with clay-slate, basalt, porphyry, and many other minerals of frequent occurrence. Along with the silicates of alumina, potash, soda, and lime found in feldspar, the silicates of iron and manganese are also present. When these silicates decompose, the bases are converted into carbonates, and silica and alumina are separated. This applies to all the silicates which are soluble in water. But even upon those which are insoluble in water,

the same decomposing action is exerted by moist car acid, and so they fall to a powder, which becomes the of the vegetable world. From this basis water takes is soluble, and in that state supplies it to plants.

The silica which has been separated is in part take by certain salts, which are soluble in water; namely, b alkaline carbonates. Through their means it is held in tion by all water, both upon and within the earth's su and is thus conveyed into the roots of plants.

All these mixed silicates of alumina, lime, potash, soda oxide of iron, produce fertile soils. Not only have the property of absorbing and holding water, but they comn retain also a large quantity of alkali,—especially if the nal mineral is not entirely decayed,—which alkali they ply to plants.

I will select, as examples, three specimens of clay fror country-(the Netherlands), taken from the Zuiderzee, lysed by E. H. von Baumhauer:—

	First.	Second.	Th
Insoluble quartzose sand, with alumina and silica,	57.646	51.706	55
Soluble silica,	2.340	2.496	2
Alumina,	1.830	2.900	2
Peroxide of iron,	9.039	10.305	11
Protoxide of iron,	0.350	0.563	0
Protoxide of manganese,	0.288	0.354	0
Lime,	4.092	5.096	2
Magnesia,	0.130	0.140	0
Potash,	1.026	1.430	1
Soda,	1.972	2.069	1
Ammonia,	0.060	0.078	0
Phosphoric acid,	0.466	0.324	0
Sulphuric acid,	0.896	1.104	0
Carbonic acid,	6.085	6.940	4
Chlorine,	1.240	1.302	1
Humic acid,	2.798	3.991	3
Crenic acid,	0.771	0.731	0
Apocrenic acid,	0.107	0.160	0
Humin, vegetable remains, and water chemically combined,	8.324	7.700	9
Wax and resin,	trace	trace	t
Loss,	0.542	0.611	0
	100.000	100.000	100

On considering the constituents of these clays, it will be clearly seen, how valuable they are for the growth of plants, and how many substances—which are really constituents of plants—are contained in them. This clay, like all the other species in Holland, derives its origin from the Rhine countries, and is thus a product of decayed rocks.

The sulphuric acid which it contains is derived from decomposed sulphurets; the phosphoric acid from apatite (phosphate of lime), a mineral which very frequently occurs. These two constituents must be present in every fertile soil.

Of an entirely opposite kind to these are our sandy soils, in which the chief part is quartzose sand. From this substance, water dissolves nothing—acids hardly anything. Unless, therefore, they are artificially mixed with the substances which are indispensable to the growth of plants, they are wholly unfit for this purpose.*

Some of the lands, reclaimed by dykes, in the province of Gröningen, have not as yet been in want of any additional alkaline salts;—while, on the contrary, the barren sandy soils in the neighbouring provinces require to be repeatedly supplied with ash from plants, to give to new plants that of which the old had exhausted the soil.†

We think it fit to conclude this exposition by a brief enumeration of some principal rocks, whose decay has given rise to the formation of soil.

Quartz-rocks.—To these belong rock-crystal, common quartz, flinty slate (quartz, with alumina, lime, and oxide of

* This is so far true; and yet these quartz sands, from which water, and even boiling acids extract nothing, do still contain small quantities of those bases, lime, magnesia, potash, &c., which plants require. Seeds sown in them sprout, and their roots extract from the sand a portion of these bases, though not enough in general to enable them to grow in a healthy manner, and to ripen their seeds. But these first races die; those which succeed find a portion of the work of extraction already performed,—they, therefore, grow better, and their successors better still; and thus a thick herbage at last covers the loose, and apparently barren ground. This fact is encouraging to the husbandman. It shows the existence of a power, so to speak, in the roots of plants, which we should not have expected, and a latent capability in soils which we are apt to pronounce hopelessly barren. See Wiegman and Polstorff, *Ueber die Anorganischen Bestandtheile der Pflanzen*, p. 32.—*J.*

† See further: Sprengel's Bodenkunde.

iron), flint* (quartz, with alumina, lime, and oxide of sandstone, and sand.

Feldspar-rocks.—To these belong granite, which co quartz, mica, and feldspar;† gneiss, in which feldspar, q and mica are contained, so as to make its composition all that of granite ; compact feldspar, which constitutes the part of clinkstone,‡ and feldspar-porphyry or keratite (and alumina, combined with potash, soda, lime, mag oxide of iron, and oxide of manganese). They contai occasional mixtures, sulphuret of iron, hornblende, and r trachyte § (silica, alumina, potash, and oxide of iron) ;] stone‖ (alumina, silica, oxide of iron, potash, and lime)

* *Flint.*

	Klaproth.
Silica, ...	98.00
Alumina, ...	0.25
Lime, ...	0.50
Oxide of iron, ...	0.25
Water and volatile matter, ...	1

Berzelius has more recently found, that flints contain a small per cen potash.—*J.*

† *Common Feldspar.*

	Vauquelin.	Berthier.
Silica, ...	64	64.20
Alumina, ...	20	18.40
Potash, ...	14	16.95
Lime, ...	2	0.00

‡ In *Clinkstone* has been found as much as 8 per cent. of potash, 9 per of soda, and 3½ per cent. of lime.

§ According to Berthier.

	From Puy de Dome.	From Pertuis.
Silica, ...	65.5	61.0
Alumina, ...	20.0	19.2
Potash, ...	9.1	11.8
Lime, ...	2.2	0.0
Magnesia, ...	0.0	1.6
Oxide of iron, ...	3.0	4.2
Water, ...	0.0	2.0

‖ *Pearlstone*, from Tokay.

	Klaproth.
Silica, ...	72.25
Alumina, ...	12.00
Potash, ... }	
Soda, ... }	4.50
Lime, ...	0.50
Oxide of iron, ...	1.60
Water, ...	4.50

pumice* (silica, alumina, soda, potash, oxide of iron, and oxide of manganese).

Mica-rocks.—To these belong mica-slate, consisting of quartz and mica,† (mica is either potash, magnesia, or lithia mica, and contains, in combination with one of these bases, silica, alumina, oxide of iron, oxide of manganese, hydrofluoric and phosphoric acids); chlorite-slate (alumina, oxide of iron, silica, lime, magnesia); and lime-slate.

Hornblende-rocks.—To this class belong hornblende‡ (magnesia, lime, silica, alumina, protoxide of iron, and manganese); and greenstone§ (a mixture of hornblende and labradorite).

* *Pumice.*

	Berthier.
Silica, ...	70.0
Alumina, ...	16.0
Oxide of iron, ...	0.6
Soda, ... } Potash, ... }	6.5
Lime, ...	2.5
Water, ...	3.0

† *Mica.*

	Potash-mica. Rose.	Magnesia-mica. Klaproth.	Lithia-mica. Gmelin.
Silica, ...	47.50	42.50	49.060
Alumina, ...	37.20	11.50	33.611
Oxide of iron,	3.20	22.00	—
Oxide of manganese,	0.90	2.00	1.420
Potash, ...	9.60	10.00	4.186
Magnesia, ...	—	9.00	0.408
Oxide of lithium,	—	—	3.594
Hydrofluoric acid,	0.56	—	3.445
Phosphoric acid,	—	—	0.112
Water, ...	2.63	1.00	4.184

‡ *Hornblende*, free from alumina, consists of—

$CaO, SiO^3 + 3MgO, 2SiO^3$ (Tremolite).

$FeO, SiO^3 + 3MgO, 2SiO^3$ (Anthophyllite).

Or— $NaO, SiO^3 + 3FeO, 2SiO^3$ (Arfvedsonite).

Hornblende, with alumina, consists of—

$CaFl + 5(CaO, SiO^3 + 3MgO, 2SiO^3)$.

§ *Greenstone.*

	Beudant.
Silica, ...	63.3
Alumina, ...	14.2
Oxide of iron, ...	5.8

The formula of labradorite is, according to the analysis of Klaproth, calculated by Berzelius:—

$$(NaOSiO^3 + Al^2O^3SiO^3) + 3(CaO, SiO^3 + Al^2O^3SiO^2).$$

Serpentine-rocks, to which belong serpentine* (magnesia, silica, lime, oxide of cerium, oxide of iron).

Augite-rocks, to which belong basalt, being an intimate mixture of augite, labradorite, or feldspar, and protoxide of iron. The whole basalt† consists of silica, alumina, oxide of iron, oxide of manganese, lime, and magnesia, with soda, or potash. The composition of dolerite nearly approximates to that of basalt.

Alumina-rocks, to which belong alumina-slate (silica, alumina, lime, magnesia, oxide of iron); often also potash, soda, gypsum, and common salt.

Lime-rocks, of which the chief constituent is carbonate of lime.

Gypsum, or sulphate of lime.

Iron, oxidulated iron, magnetic oxide of iron, iron-slate.

We perceive that the substances above enumerated, and which after their decay cover so large a portion of the earth's

Lime, ...	2.5
Magnesia, ...	2.0
Potash, ...	1.2
Soda, ...	1.2
Water, ...	0.3

* *Serpentine*, after Mosander and Lychnell.

$$3MgO, 2HO + 2(3MgO, 2SiO^2).$$

† *Basalt*, from Stettin in Hoegan. Gmelin.

	Part soluble in acids.	Part insoluble in acids.
Silica, ...	35.741	48.500
Alumina, ...	11.121	6.792
Oxide of manganese, ...	1.487	—
Oxide of iron, ...	—	9.383
Protoxide of iron, ...	16.015	—
Lime, ...	11.914	17.395
Strontian, ...	0.112	—
Magnesia, ...	10.434	13.131
Soda, ...	3.264	—
Potash, ...	1.204	—
Water, ...	6.530	—

surface, contain for the most part, the same constituents. Their real difference consists either in their less important ingredients, or in the various proportions they contain of the several constituents, whose mutual combinations form the several minerals. Hence it is clear, that in different parts of the earth's surface, they must be very different.

These rocks, which covered the earth in the beginning, and which, during the long period of their existence, have been gradually crumbling down, have thus produced the inorganic constituents of the soil, and are every day still doing so.

By the condensation of the four elements, carbon, hydrogen, nitrogen, and oxygen, from the atmosphere upon the earth during the first growth of plants—by the continual increase of this condensation in living plants, and by the production therefrom of the black organic substance, which we now find in the ground,—this black substance must have been immediately mixed with the fragments of the decayed rocks. The final result of this process must necessarily have been the production of a mixture, in which inorganic compounds, both alone and in combination with organic compounds, would be found. On considering the chief inorganic constituents of the soil briefly enumerated above, we see that such of them as are soluble in water, are the same with those which we formerly noticed as being also found in common water, owing to the facility with which they are dissolved out of the decayed rocks, either by the falling rain water, or by the melted snows. And as these salts are also indispensable constituents of plants and animals, the whole inorganic earth appears to be in intimate relation with organic nature, and *vice versa*. Finally, the substances soluble in water are mixed both with the organic constituents of the soil, and with the insoluble remains of decayed rocks; and so they are supplied to plants in a finely divided state.

Supposing the products of the decomposition of plants and of animals to be the very same, in certain circumstances, it is still impossible that the several kinds of soil should be the same in different places. The inorganic substances present in the soil influence this decomposition, and frequently mo-

dify it. The presence of bases, acids, or salts,—all acting so powerfully in inducing changes among the elements of organic substances,—must necessarily influence the decomposition of plants and animals, and the products which result from it, and thus also the motion imparted by the decomposing molecules of the black crust of the earth to the plants which grow there. Hence the difference of soils arising from a difference in their inorganic parts—hence the difference in the new products, which spring from the soil, according as the inorganic constituents of the earth's crust differ; hence, in other words, the relation between the rocks of any district, and the vegetation which grows upon their decaying fragments.

It is a known fact, that the Flora of our country (the Netherlands), agrees with that of the whole district on the Rhine.* This is justly ascribed to the diffusion of seed by means of the waters of the Rhine; but another cause may be superadded, namely, the uniformity of the inorganic parts of the soils, carried down by the stream.

In different plants, different constituents of the salts, bases, and acids are found. It may be true, that substances, to which they are nearly allied, may be substituted for them, as potash for soda, &c.; but every species of plant preserves a high degree of peculiarity in this respect, and often dies from want of its peculiar inorganic constituents.

Hence the reason why certain plants prefer certain soils—why they refuse to live in some tracts of land, though in other respects they are placed in the same circumstances: hence the necessity that fields, from which plants are continually reaped, should have the ash of plants occasionally added; hence, finally, the increased fertility of pastures irrigated by the winter floods, which restore the inorganic substances of which the soil has been exhausted by its vegetable produce.

A fertile arable soil, therefore, is an intimate mixture of inorganic substances, insoluble in water,—especially fitted to make the soil penetrable, by the roots of plants, and by water; or, by their hygroscopic force, to retain the water, a

* Miquel, Distributio Geographica Plantarum.

property of which clay is possessed in a very high degree—or of substances soluble in water, which can be taken up by plants, and to which the salts already enumerated belong. It is a mixture, also, of organic with inorganic substances, with the latter of which the former may or may not be combined.

These organic substances existing in the soil, would be of an incalculable variety, if they were not, by a general cause, reduced to a small number. If this general cause did not exist, the first plants produced on the decayed rocks would, when dying, have deposited on the earth's crust all their materials; to these, the succeeding plants would have added their share—and thus there would have been formed everywhere a mixture of all sorts of vegetable substances, differing with the nature of the materials, from which different tribes of plants are built up. In nature, however, this operation proceeds in a very different way.

Not only is the individual destroyed at its death, but all its organic substances are decomposed, transformed, changed, and modified in such a manner, that, finally, a few only are produced, whatever may have been the plant or the animal whose individuality was destroyed. There are, however, some vegetable as well as animal substances, in which this common change is not yet known; nor is it likely to take place. As to these, the inquiry still remains, what becomes of them in the earth's crust? The resins, fats, vegetable bases, and acids are of this class. As to the chief component parts of the organic kingdom, however, it is known into what they are transformed during their decay in the soil, that is, during the formation of humus. This decay is a peculiar decomposition of organic bodies, not to be confounded with putrefaction, from which it greatly differs; owing, especially, to the influence of the decayed rocks, and the division of the organic substances, effected by this cause. This change is remarkably uniform, since, from the innumerable organic combinations which exist in plants and animals, the same few constituents of the black layer of soil are derived.

If we exclude the substances accidentally mixed with the black soil, as well as those substances which have not yet

undergone sufficient decomposition, its constituents are limited to a small number of organic substances—substances existing in it everywhere, and on the decomposition of which the growth of plants depends.

These substances have the following properties:—Some of them are soluble in water, others in alkalies, others again are insoluble in both, while some dissolve more or less readily in alcohol and ether. The latter are resinous substances, and they appear to have no share in vegetation at all. The resins obtained from turf are of an exceedingly singular composition, which indicates that they contain combinations of carbon and hydrogen, in different proportions—namely, CH, and C^5H^4—either combined or not combined with oxygen.

In the hard Frisian turf, 4 resins exist:*—

α. $C^{50}\ H^{40}\ O^9 = 10(C^5H^4) + O^9$.
β. $C^{77}\ H^{67}\ O^9$
γ. $C^{104}H^{94}\ O^9$
δ. $C^{131}H^{121}O^9$

In the three latter, the α resin is no doubt chemically combined with carburretted hydrogen, CH, for if, from each of them, we subtract the α resin, we have:—

1° β. $C^{77}H^{67}O^9$
α. $C^{50}H^{49}O^9$
$C^{27}H^{27} = 9 \times C^3H^3$

2° γ. $C^{104}H^{94}O^9$
α. $C^{50}\ H^{40}O^9$
$C^{54}\ H^{54} = 18 \times C^3H^3$

3° δ. $C^{131}H^{121}O^9$
α. $C^{50}\ H^{40}\ O^9$
$C^{81}\ H^{81} = 27 \times C^3H^3$

In long Frisian turf, the composition of these resins is somewhat different:—

* Bulletin, 1839, p. 147.

$C^{35} H^{28} O^5 = 7 (C^5 H^4) + O^5$
$C^{20} H^{168} O^6 = 6 (C^5 H^4 + O) 60 (C H).$*

These are all the substances of this kind which, so far as they exist in the soil, have been as yet investigated. But similar substances, produced from the decomposition of organic bodies, exist undoubtedly in all sorts of soils, and in other strata. The light carburetted hydrogen, $C H^2$, is a product resulting from the decomposition of plants, which have been buried under the ground to a great depth, and transformed into coal. There are two other carburetted hydrogen compounds, C H and $C^5 H^4$, which have a solid form, and by a similar change are produced at the surface. It is very likely that further investigation will make us acquainted with more of them. (Johnston.)

* Resinate of lead, hard Frisian turf.

	Found.	Atoms.	Calculated.
C	57.33	50	57.77
H	7.81	40	7.55
O	13.44	9	13.61
PbO	21 42	1	21.07

† Resin.

	Found.	Atoms.	Calculated.
C	77.37	77	77.21
H	10.98	67	10.97
O	11.65	5	11.82

‡ Resin

	Found.	Atoms.	Calculated.
C	79.12	104	79.32
H	11.94	94	11.79
O	8.94	9	8.98

§ Resin

	Found.	Atoms.	Calculated.
C	80.77	131	80.60
H	12.15	121	12.15
O	7.08	9	7.25

‖ Resin, long Frisian turf.

	Found.	Atoms.	Calculated.
C	76.20	35	75.89
H	10.21	28	9 92
O	13.59	5	14.19

¶ Resin

	Found.	Atoms.	Calculated.
C	80.38	90	80.68
H	12.52	84	12 29
O	7.10	6	7.03

2° The organic substances which are soluble in water and alkalies, are present in certain kinds of soil in considerable quantity, in others to a very small extent. Their characters are analogous to those of the substances which are insoluble in water and alkalies, with the exception of the resins above mentioned. These soluble substances present themselves with different characters in the soil, owing to their being combined with different inorganic bodies; the same organic substance, which forms a soluble compound with potash, forming an insoluble one with oxide of iron or lime. There are, however, two organic constituents of the soil which do not combine with bases, and are insoluble both in water and in alkalies.

At present seven different organic substances are known to exist in the soil. They are crenic acid, apocrenic acid, geïc acid, humic acid and humin, ulmic acid and ulmin. Humin and ulmin are insoluble in alkalies and in water; the others are readily soluble in alkalies, and more or less in water also. In different kinds of soils the relative proportions in which these substances are present, are very different, as are many of their physical and chemical properties; but numerous experiments seem to show, that a greater number cannot at present be admitted.*

It is of importance to be acquainted with these substances. I shall divide them into two groups, the crenic and the humic. In the latter, I include geïc acid, humic acid and humin, ulmic acid and ulmin; in the former, crenic acid and apocrenic acid.

In a good arable soil—that is, one of which the organic constituents are as far as possible decomposed—none of these substances contains nitrogen as a constituent element. All their nitrogen exists in the state of ammonia. And as five of the constituents of the soil already enumerated are acids, five different salts of ammonia, and also double salts of potash, soda, lime, magnesia, and oxide of iron, may be formed from these five acids; which salts, being soluble in water, can be supplied to plants in a state of solution.

* In a subsequent page I shall state the result of some researches of my own, which show that to this number others may already be added.—*J.*

If the soil is exhausted by means of water, a great many salts are extracted from it. Three different kinds of soil gave of salts in 100 parts:*—

0.424
2.771
1.540

These salts are the chlorides of sodium, potassium, calcium, magnesium, and ammonium, with formic, acetic, sulphuric, carbonic, crenic, apocrenic, and humic acids, in combination with the oxides of the same metals. They form altogether what is called *humus extract.*

From the soils treated with water in the manner described, alkaline solutions extract substances, which may be precipitated by acids. In different kinds of soils the substances thus extracted are sometimes different. They all consist, however, of one or more of the following three, namely:—

Geïc acid,	$C^{40} H^{12} O^{14}$
Humic acid,	$C^{40} H^{12} O^{12}$
Ulmic acid,	$C^{40} H^{14} O^{12}$

The latter is that which, in neutral vegetable substances undergoing decay, is formed first. From it, by absorption of oxygen from the air, humic acid is produced, and finally, by a further absorption, geïc acid.

Of these three substances—soluble in alkalies, and precipitable by acids from their solutions—the above-mentioned three kinds of soils gave in 100 parts:†—

4.249
5.289
8.667

The substances which are insoluble in alkalies (ulmin and humin), can be rendered soluble, and so converted into ulmic and humic acids respectively, by the decomposition which is always going on in the constituents of the soil.

The organic substances now enumerated, which in the

* Scheikundige Onderzoekingen, vol. ii. page 92.

† Scheikundige Onderzoekingen, ii. page 92.

mass we call *humic*, may thus in part be supplied to plants, provided there be an alkali at hand to bring them into a soluble state. This may be either one of the fixed alkalies, or ammonia—especially the latter, which, in a way I shall presently describe, may be so easily formed from the atmospheric air included in the soil. In this way, the humic substances, in a state fit for supplying food to plants, are added to the soluble salts above enumerated—provided ammonia have access to render them soluble in water—and, therefore, they *must* be taken up by the roots of plants, along with the salts, unless plants be able to select—a supposition which is by no means probable.*

In the fluid, from which the humic substances have been precipitated by an acid, apocrenic and crenic acids are still contained, which substances may also be collected, and their proportion calculated by adding first acetate of copper, and afterwards carbonate of ammonia. By the former, apocrenate of copper is thrown down, in which about 50 per cent. of apocrenic acid is contained; by the latter, crenate of copper, which contains a variable proportion—from 40 to 70 per cent. —of crenic acid. When treated in this way, the three soils referred to gave respectively—

Apocrenate of Copper.

1.865
1.228
0.701

Crenate of Copper.

0.774
1.901
1.260

These two acids, also, as they exist in the soil, can be separated from their insoluble combinations with lime and oxide of iron, by means of ammonia, potash, or soda, with which they form soluble salts. If ammonia, therefore, be present, the soil will

* Some of the reasons in support of the opposite view, which I am inclined at present to regard as the more probable, will be found in my published "Lectures on Agricultural Chemistry and Geology," p. 112.—*J.*

be found to contain five different compounds of this base, sometimes in considerable quantity,—substances which can be supplied to plants in a soluble state, and which are thus of great importance to their growth.

In giving a slight outline of the production of all these substances, and of their influence on the life of plants, we shall begin with the humic, and treat afterwards of the crenic group.

First, however, we must advert to the ammonia, which so powerfully supports the growth of plants, and deserves to be particularly noticed, not only as a base, rendering the five acids above mentioned soluble (in which respect, like the ashes of plants, so valuable as a manure, it plays an important part), but also as a substance containing nitrogen, the only one, indeed, of this kind, which exists in a soil sufficiently decomposed.

We are, I believe, entitled to conclude, from the experiments of Liebig himself (page 103), that this ammonia cannot be carried down to the soil from the atmosphere, by means of the rain-water. It exists in the atmosphere in too small a proportion—a proportion which has never been determined Nay, it is so minute, that it appears not to be capable of being determined,—its mere presence even is difficult to be detected.

Nitrogen, in the state of pure gas, and also atmospheric air, are, however, possessed of one common property, namely, that when in contact within an enclosed space with putrefying substances,—from which hydrogen is in consequence given off, —the nitrogen combines with the hydrogen and forms ammonia. This property of nitrogen is known. It is the principle on which saltpetre is formed; the production of that substance, as has been correctly remarked by Liebig, being always preceded by that of ammonia. Now, air is contained in the soil, and is in continual contact with moist and decomposing substances. This air could produce saltpetre, if there were only a sufficient abundance of bases, and that even without the presence of putrefying organic substances. There are in Ceylon twenty-two natural saltpetre grottos, where there are no organic substances, from which nitrogen might be supplied. Nitro-

gen is derived from the air contained in these caverns, and, in favourable circumstances, even the water is decomposed, and ammonia at the same time produced, which afterwards is oxidized into nitric acid by the oxygen of the air, in places where it has more easy access; this acid then combines again with the bases from the walls of the grottos, and forms nitrates.

All this would happen in the soil if organic substances were not present to absorb the oxygen, and thus to prevent the oxidation of the nitrogen in the ammonia, and the formation of saltpetre.

In a porous soil, in which moist air is contained, nitrogen combines with the hydrogen of the organic bodies only into ammonia, the oxygen from the water and the air being consumed in the higher oxidation of the organic substances themselves. In this way, the first product of the decomposition of organic substances, namely, ulmic acid, $C^{40}\ H^{14}\ O^{12}$, is converted into humic acid, $C^{40}\ H^{12}\ O^{12}$, and this again into geïc acid, $C^{40}\ H^{12}\ O^{14}$; the latter, again, being then further oxidized into apocrenic and crenic acids, which we intend to treat of hereafter.

It may be enough to repeat here, that in the soil, as in the natural caverns of Ceylon, the ammonia is produced from the nitrogen of the atmosphere, and that the oxygen of the air converts the organic substances successively into ulmic, humic, geïc, apocrenic, and crenic acids, instead of forming nitric acid.

What is said here of the formation of ammonia from the nitrogen of the atmosphere, contained in the moist soil, has been treated of elsewhere at greater length. (Scheik. Onderz., vol. ii.)

By all porous substances, therefore, ammonia is produced—provided they are moist, are filled with atmospheric air, and are exposed to a certain temperature.* It is by this process, that the porous lime in the walls of moist rooms comes to contain first ammonia, and afterwards nitrate of lime,—that

* See Kuhlman upon the formation of saltpetre, in Annalen der Pharmacie, Bd. 29, s. 272, who ascertained, in 1839, that the formation of ammonia precedes that of saltpetre.

moist charcoal becomes impregnated with ammonia, and forms, afterwards, by oxidation, the substances resembling humus extract, which Büchner found in charcoal to the amount of 2 per cent., and in which Lucas cultivated plants—substances consisting chiefly of apocrenate of ammonia, produced from the charcoal by oxidation.

This formation of ammonia from the nitrogen of the atmosphere has been denied by several writers, especially on the ground, that at an elevated temperature nitrogen does not form any combination with hydrogen. But the combination of nitrogen with hydrogen at ordinary temperatures, in various circumstances, is equally true with the result of the experiments made upon the former point. It has been demonstrated by many experiments, that, at an elevated temperature, nitrogen has an indifferent character, being unable to form direct combinations at a red heat, either with hydrogen or with oxygen. This is, however, not the case with regard to carbon. Coke, when heated to redness with potash in the open air, produces cyanuret of potassium. There are some circumstances also in which nitrogen does combine with oxygen at a high temperature:—for instance, Cavendish obtained nitric acid by passing electric sparks through moist atmospheric air, and the same acid is also produced, when a mixture of hydrogen and nitrogen is burned in the air.

It is a fact, especially important to our present purpose, that hydrogen, *in the nascent state*, combines directly with nitrogen into ammonia. When reddened litmus paper is hung up in a bottle, filled with pure atmospheric air, and when pure iron-filings, moistened with pure water, are laid at the bottom, then the red litmus is quickly turned blue by the action of ammonia, formed from the nitrogen in the air, and the hydrogen of the decomposed water, the oxygen of which had combined with the iron.

Such a formation of ammonia continually takes place in the soil. There, atmospheric air is present, and consequently nitrogen; hydrogen is continually liberated (see below), and thus the conditions, necessary to the formation of ammonia, are fulfilled as often as cellulose, ligneous matter, starch, &c.,

are changed either into humic acid, or into other constituents of the soil.

To this formation of ammonia from the constituents of atmospheric air and water, we must look for the cause of one of the most important peculiarities in the growth of plants. It is owing to this slow formation of ammonia, that the organic substances of the soil, insoluble in water, are rendered soluble, and so can be offered to plants as organic food, even without a supply of ammoniacal manure to the soil. In other words, it is owing to this cause, that the five acids already mentioned can all be converted into soluble ammoniacal salts.

The *humic substances*,—that is, the substances which can be extracted from the soil by alkalies, and precipitated from the alkaline solution by acids—from whatever kind of soil they may have been prepared, have a very great uniformity, and are remarkably similar to those substances which, by the action of several chemical agents, may be obtained from the materials which are generally diffused through the vegetable and animal kingdoms. Hence, we perceive *a remarkable conformity* between putrefaction and chemical action, and also a change of very dissimilar bodies into the same substances, by which we are led to recognise a certain conformity in the natural arrangement of the elements of these bodies. While, therefore, we see woody fibre, starch, gum, sugar, and also protein, severally yield the same chemical substances by means both of putrefaction and of an acid, and woody fibre by means of putrefaction, an acid, or heat (in soot),—we have undeniable proof, that putrefaction, acids, and heat, must exert on these substances the same effect, and consequently their chemical influence must be uniform. Putrefaction being thus a chemical action, and at the same time a phenomenon which immediately succeeds the individual vital force, we are, in spite of ourselves, led to draw the conclusion, that this individual vital force is very much regulated by chemical action, though it may be determined by other series of chemical actions, than those by which putrefaction is effected.

But we are not less entitled to draw the conclusion, that,

as the same substances are produced in circumstances so very different (putrefaction and the action of acids), and from so many different materials (woody fibre and protein, starch and phloridzine*),—there must exist in all these dissimilar complex substances (viz., protein, woody fibre, starch, gum, sugar, phloridzine, and a great many others), a uniform arrangement of the molecules, or some unknown combination of the elements, which occurs as a prototype in humic acid and humin, and which is constantly liberated from these different substances under very different circumstances. This presents another generality in the arrangement of the organic world, and exhibits in a beautiful light the simplicity of the whole scheme.

3° The soil contains a humic substance, which is insoluble in alkalies. A similar one is found also in the products obtained by the action of acids upon sugar, &c. The composition of the latter is known. That of the former is very difficult to ascertain, because the different insoluble products of putrefaction remain in a state of mixture, and can scarcely be completely separated—such, for instance, as rotten wood, which cannot be separated from that which is but partly rotted. We may, however, suppose, with a certain degree of probability, that the substance of the soil, which is insoluble in alkalies, will also be similar to that which can be produced from sugar, &c., by means of acids.

The humic substances, soluble in alkalies, are divisible into three classes according to their composition—into those, namely, which can be supposed to consist of carbon and the elements of water,—those which contain more hydrogen than the oxygen requires to form water,—and those which contain an excess of oxygen. Such are the humic, ulmic, and geïc acids. Their composition is as follows:†—

* Nitro-humic, and nitro-phloretic acid are identical; they are both apocrenate of ammonia (Scheik. Onderzoek., vol. ii. p. 105).

† Bulletin, 1840, p. 1.

Ulmic acid from sugar, at 195° Cels. (383° Fahr.)

	Found.	Atoms.	Calculated.
C	68.95	40	68.98
H	4.23	14	3.94
O	26.82	12	26.08

	C	H	O		HO		O
Ulmic acid from sugar by means of acids, ...	40	14	12				
Ulmin from the same, ...	40	14	12	+	2		
Ulmic acid from long Frisian turf,	40	14	12	+	4		
Humic acid from sugar by means of acids, ...	40	12	12				
Humin from the same, ...	40	12	12	+	3		
Humic acid from hard turf, ...	40	12	12	+	3		
Humic acid from a rotten tree,	40	12	12	+	4		
Humic acid from an arable soil,	40	12	12	+	4		
Humic acid from soot, ...	40	12	12	+	4		
Geïc acid from two kinds of soil,	40	12	12	+	3	+	2
Humic acid from a pasture field,	40	12	12	+	2		
Humic acid from an arable soil,	40	12	12	+	5		
Humic acid from protein, by means of muriatic acid, ...	40	12	12				

Almost all these substances are combined with ammonia in

Ulmin at 140° Cels. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	65.27	40	65.65
H	4.52	16	4.28
O	30.21	14	30.07

Ulmic acid from long Frisian turf, at 140° Cels. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	61.85	40	62.62
H	4.79	18	4.62
O	33.36	16	32.76

Humin from sugar, at 140° Cels. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	64.67	40	64.44
H	4.32	15	3.94
O	31.01	15	31.62

Humic acid from sugar, combined with oxide of silver, at 100° C. (212° Fahr.)

	Found.	Atoms.	Calculated.
C	49.05	40	49.36
H	3.23	15	3.02
O	24.58	15	24.21
AgO	23.14	1	23.41

the soil, and contain different proportions of water, with which they remain in combination, if dried at the same temperature of 140° Cels. (= 284° Fahr.). They ought, therefore, not to be considered as the same, though analogous substances; they differ from each other in accidental, and not in essential, properties. The varieties of the three acids—ulmic, humic, and geïc acids—must be viewed in the same light as the different kinds of sugar, in which it is clear, that $C^{12} H^9 O^9$ is contained, but from many of which the whole of the water cannot be driven off by bases. (See Scheikund. Onderz., vol. ii. page 88.)

Let us now briefly consider the manner in which the above three acids are produced.

Ulmin and ulmic acid are formed from cellulose, starch,

Humate of ammonia from hard Frisian turf, at 140° C. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	0.13	40	60.28
H	4.74	19	4.68
N	3.61	1	3.49
O	31.55	16	31.55

$= C^{40} H^{19} O^{13} + N H^3 + 4 H O$

Humate of ammonia from an old willow, at 140° C. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	59.06	40	58.98
H	4.96	20	4.82
N	2.80	1	3.41
O	33.18	17	32.79

$= C^{40} H^{19} O^{13} + N H^3 + 5 H O$

Geate of ammonia from an arable soil, at 140° C. (284° Fahr.)

	Found.	Atoms.	Calculated.
C	57.37	40	58.00
H	4.43	19	4.48
N	3.25	1	3.37
O	34.95	18	34.15

$= C^{40} H^{19} O^{14} + N H + 4 H O^2$

Humate of ammonia from an arable pasture soil (284° Fahr.)

	Found.	Atoms.	Calculated.
C	57.16	40	56.63
H	5.38	23	5.32
N	6.11	2	6.56
O	31.35	17	31.49

$= C^{40} H^{19} O^{13} + 2 N H^3 + 5 H O.$

gum, and sugar, by the influence of acids, and at the same time, formic acid is produced. The following may serve as an example:—

		C	H	O
½ of 7 equiv. of sugar,	= ...	42	35	35
1 equiv. of of ulmin,	= ...	40	16	14
1 equiv. of formic acid,	= ...	2	1	3
18 equiv. of water,	= ...		18	18
		42	35	35

It is certain, that a change similar to the above takes place during the formation either of ulmin or ulmic acid from cellulose or other neutral substances during decay. In this case, however, the formic acid either cannot be produced at all, or cannot be so exclusively; but, in its stead, two equivalents of carbonic acid and one of water must be produced, two of oxygen being absorbed from the air.* In the same manner the above organic substances are changed into humin and humic acid, which are formed in the soil more frequently than ulmin and ulmic acid, and consist of $C^{40} H^{12} O^{12}$. They are produced from sugar, by the action of acids, with access of air, as follows:—

Humate of ammonia from a garden mould, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	57.87	40	57.72
H	4.98	21	4.97
N	3.52	1	3.34
O	33.53	18	33.79

$= C^{40} H^{12} O^{12} + N H^3 + 6 H O$

Humate of ammonia from protein by means of muriatic acid, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	64.86	40	64.58
H	4.61	16	4.22
N	3.70	1	3.74
O	26.83	13	27.46

$= C^{40} H^{12} O^{12} + N H^3 + H O$

* These two of oxygen are required to convert the formic acid into carbonic acid and water. Thus:—

Formic acid + 2 of oxygen = 2 of carbonic acid + water.
$C^2 H^1 O^3 + 2 O = 2 C O^2 + H O$

	C	H	O
⅛ of 7 equiv. of sugar, ...	42	35	35
1 equiv. of humin, ...	40	12	12
1 equiv. of formic acid, ...	2	1	3
22 equiv. of water, ...		22	22
	42	35	37

Thus, *two* equivalents of oxygen are taken from the atmosphere, when humin is formed in this way. In the soil, again, during the decomposition of sugar, *four* of oxygen are absorbed, and two of carbonic acid, and one of water, are formed, instead of one of formic acid. (See preceding note.)

The change of sugar, therefore, either into humin or ulmin, or into their acids, during decay, is a simple transposition of its elements. Thus ulmin is formed from it, with absorption of two of oxygen, humin of four of oxygen, and geïc acid of six of oxygen, as follows:—

	C	H	O
⅛ of 7 equiv. of sugar, + O^2,	42	35	37
2 equiv. of carbonic acid,	2		4
19 equiv. of water, ...		19	19
1 equiv. of ulmin, ...	40	16	14
	42	35	37
⅛ of 7 equiv. of sugar, + O^4,	42	35	39
2 equiv. of carbonic acid,	2		4
23 equiv. of water, ...		23	23
1 equiv. of humin, ...	40	12	12
	42	35	39
⅛ of 7 equiv. of sugar, + O^6,	42	35	41
2 equiv. of carbonic acid,	2		4
23 equiv. of water, ...		23	23
1 equiv. of geïc acid,	40	12	14
	42	35	41

As to cellulose, starch, gum, inuline, and lichen starch, what has been said with regard to sugar, holds true of them also. Pectin, and other analogous substances, which are so very much diffused through plants, do not require any oxygen from the air, to be converted into humin. They consist of $C^{12}\ H^{8}\ O^{10}$; and thus, taking the same tabular view as for sugar, they would give:—

	C	H	O
½ of 7 equiv. of pectin,	42	28	35
2 equiv. of carbonic acid,	2		4
16 equiv. of water, ...		16	16
1 equiv. of humin, ...	40	12	12
	42	28	32

There is here, then, a remainder of three equivalents of oxygen, so that cellulose, starch, sugar, &c., if mixed with a certain quantity of pectin, might produce humus, and give off a certain quantity of carbonic acid to the atmosphere, without taking from it any oxygen.

Of these neutral materials, plants chiefly consist, and it is highly probable that their decomposition is effected in the manner above described. There are some organic substances, of which the mode of conversion into humus cannot, with any probability, be demonstrated: with many, however, it might be; but the illustrations already presented in regard to such of the neutral vegetable substances as are most generally diffused, may suffice for the present.

There is one of the chief component parts, belonging both to the bodies of animals and of vegetables, the change of which into humus is equally simple. This substance is protein. By the influence of hydrochloric acid, and the oxygen of the air, it is converted into humic acid, in the following manner:*—

* Bulletin, 1840, p. 74.

	C	H	N	O	Cl
1 equiv. of protein,	40	31	5	12	
4 equiv. of hydrochloric acid,		4			4
4 equiv. of oxygen,				4	
	40	35	5	16	4

From these are produced:—

	C	H	N	O	Cl
1 equiv. of humin,	40	15		15	
1 equiv. of ammonia,		3	1		
1 equiv. of water,		1		1	
4 equiv. of chloride of ammonium,		16	4		4
	40	35	5	16	4

In the formation of humus from protein, again, humin and ammonia are produced; four equivalents of oxygen being absorbed from the air:—

	C	H	N	O
1 equiv. of protein, + O^4,	40	31	5	16
1 equiv. of humin, ...	40	15		15
1 equiv. of water, ...		1		1
5 equiv. of ammonia, ...		15	5	
	40	31	5	16

The other chief constituents of the animal body have not been investigated with reference to these transformations; so that it is not known what kind of changes they undergo in the soil, when they are converted into humus.

Though it be true, that the products of the decomposition of organic substances differ with circumstances, and, consequently that, in the above outline, the decomposition is stated for one particular case only; yet it results from what has been said, that the same substances, of which the black layer of soil chiefly consists, are formed from the most different products of the vegetable and animal kingdom, especially from

their chief constituents—*both* by the influence of chemical agents, and by that of the formation of humus.

The ulmic, humic, and geïc acids, however prepared, have the property of condensing ammonia and water, to the extent of several parts per cent. This water cannot be separated from them, unless they are exposed to a very high temperature. We have observed that from 8 to 16 per cent. of water are given off at 284° Fahr. from different kinds of humin and ulmin.* They can be entirely deprived of water, only by a temperature of 383° Fahr. By this great hygroscopic power, the growth of plants is very materially promoted. In the soil, humic and geïc acids are always combined with ammonia. All the ammonia, produced by the decay of substances containing nitrogen, (protein from plants and animals, &c.;)—and all that is formed in the porous soil from the component parts of the atmosphere and of water—combines with the humic and geïc acids, into humate and gëate of ammonia, which are severally present in different kinds of soils. We have found, in different specimens of soils and turfs, humates and gëates of ammonia, which, at a temperature of 284° Fahr., had the following composition :—

Turf, ...	$C^{40} H^{12} O^{12}$	$+ N H^3 + 4 H O$
Decayed tree,	idem	$+ N H^3 + 5 H O$
Soil from an orchard,	idem	$+ 2N H^3 + 4 H O + O^2$
Garden mould,	idem	$+ 2N H^3 + 4 H O + O^2$
Soil from pasture land,	idem	$+ 2N H^3 + 5 H O$
Garden mould, planted with young oaks,	idem	$+ N H^3 + 5 H O$
Garden mould, planted with currant bushes,	idem	$+ N H^3 + 6 H O$

This power of condensing ammonia, possessed by the ulmic, humic, and geïc acids, is so powerful, that the acid, prepared from sugar by means of muriatic acid, contains almost always ammonia, unless the air be carefully excluded. The ammonia, which always either exists in the atmosphere, or is produced from it in the manner above mentioned (p. 149) :

* Bulletin, p. 10, 47, 50.

(for instance, the ammonia, from which the incrustations round the necks of bottles, containing phosphoric acid, &c., and the collections of liquid on the necks of bottles, containing nitric acid, &c. are formed,) combines with the geïc, humic, and ulmic acids, and thus gëate, humate, and ulmate of ammonia are produced. By this property, Hermann was, no doubt, misled, when he thought that the humic acid from sugar contained nitrogen.* We may ascribe to it a very important function of the soil. It enables these acids to retain ammonia, either condensed from the atmosphere, or formed from its constituents, and thus to supply nitrogen to plants—to absorb the ammonia formed during the decay of substances which contain nitrogen—and greatly to promote the growth of plants by means of nitrogenous manures.

It is by this ammonia also, that the geïc, humic, and ulmic acids of the soil are made soluble in water, and so fitted to be taken up by the roots of plants, in the same manner as so many inorganic salts, such as the alkaline sulphates and chlorides, are taken up by them. Thus, the ammonia is an additional base in the soil, and joins the potash, magnesia, soda, lime, and the oxides of iron and manganese, to form a long series of ulmates, humates, and gëates, some of which are soluble, and others insoluble in water.

As the proportion of ammonia increases, more of the other bases—for instance, oxide of iron and manganese—are displaced by it, and in this way gëates, humates, or ulmates, which are either insoluble, or soluble with difficulty, are converted into the very soluble gëate, humate, or ulmate of ammonia. Thus, as substances, giving off ammonia, decay in the soil, they must produce soluble gëate, humate, or ulmate of ammonia.

4° These remarks may suffice in regard to the humic substances in the soil, that is, such as can be extracted from it by alkalies, and precipitated by acids from the alkaline solution. There are two other constituents of the soil, however, which deserve particular attention, viz., the *crenic* and *apocrenic acids*.

* Journal für Praktische Chemie, 1841, Erster Band, p. 68. The whole treatise of Hermann, in this and the following parts, 1841, Part II. p. 375, and 1842. Part I. p. 182, proves of itself the inaccuracy of his results.

Both of these, like the humic acids, exist in the soil as double-salts, that is, in the state of salts of ammonia, potash, and soda, combined with lime, magnesia, and oxide of iron; being also partly soluble, and partly insoluble in water, and changeable into soluble salts by means of ammonia.

The composition of these acids is the following:—

Apocrenic acid, ... $C^{48} H^{12} O^{24}$
Crenic acid, ... $C^{24} H^{12} O^{16}$

These acids, of course, never exist uncombined in the soil. They unite intimately with ammonia, so as to exhibit the characters of quaternary substances. Treated with potash, however, at an elevated temperature, this ammonia is completely separated. But these acids are also combined in the soil with other bases, in such a manner, that the ammonia forms almost always a component part of a double apocrenate or crenate of potash, soda, lime, magnesia, or oxide of iron.

From the three soils above mentioned (p. 146), as well as from others, the following crenates and apocrenates were obtained, either in the state of double apocrenates, or of simple crenates of ammonia and of copper, according to the mode of preparation. These acids, like the ulmic, humic, and geïc acids, are extremely difficult to dry, and when dried at the same temperature, they retain different proportions of water, which increases as the quantity of base, in combination with the acid, decreases. From these soils were obtained apocrenates of oxide of copper and of ammonia, the organic constituents of which gave the following formulæ:—

$$C^{48} H^{12} O^{24} + 1\tfrac{1}{2}\ N H^3 + 5\ Aq.$$
$$C^{48} H^{12} O^{24} + \tfrac{1}{2}\ N H^3 + 10\ Aq.*$$

The apocrenic acid is an acid which saturates five equivalents,

* Scheik. Onderzoek. Vol. ii. p. 99.
Apocrenate of ammonia, from two kinds of soils, at 284° Fahr.

	Found.		Atoms.	Calculated.
	I.	II.		
C	51.89	50.83	48	51.66
H	3.75	4.16	$21\frac{1}{2}$	3.78
N	3.37	4.09	$1\frac{1}{2}$	3.74
O	40.99	40.92	29	40.82

$= C^{48} H^{12} O^{24} + 1\frac{1}{2}\ N H^3 + 5\ H O$

either of base or of water. It is thus a five-basic acid,—at least the artificial acid is so. That which exists in the soil may, perhaps, be able to combine with a greater number of equivalents of water, or of bases, as the humic class of acids does.

There are several modes of preparing an artificial apocrenic acid, two of which are of especial importance, in connection with the subject we are now considering.

Apocrenate of ammonia, from two other kinds of soils, at 284° Fahr.

	Found. I.	Found. II.	Atoms.	Calculated.
C	48.37	48.18	48	49.24
H	3.90	4.04	23½	3.94
N	1.11	1.48	½	1.19
O	46.62	46.30	34	45.63

$= C^{48} H^{23} O^{34} + \frac{1}{2} N H^3 + 10 H O$

Apocrenate of ammonia, from humic acid prepared from sugar by nitric acid, at 230° Fahr.

	Found.	Atoms.	Calculated.
C	55.43	48	55.10
H	3.49	17	3.19
N	2.98	1	2.66
O	38.10	26	39.05

$= C^{48} H^{17} O^{26} + N H^3 + 2 H O$

Neutral apocrenate of ammonia and lead, at 230° Fahr.

	Found.	Atoms.	Calculated.
C	28.97	48	29.98
H	1.88	17	1.73
N	1.80	1	1.45
O	22.67	26	21.20
PbO	44.68	4	45.64

$= C^{48} H^{13} O^{24} + N H^3 + 4 Pb O + 2 H O$

Anhydrous apocrenic acid.

	Found.	Atoms.	Calculated.
C	59.06	48	59.00
H	2.87	12	2.41
O	38.07	24	38.59

Crenate of ammonia from an arable soil, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	45.98	24	45.59
H	5.50	17	5.27
N	3.88	1	4.41
O	45.64	18	44.73

$= C^{24} H^{13} O^{16} + N H^3 + 2 H O$

When humic acid, in whatever way prepared, or wood charcoal, is exposed to the action of nitric acid, apocrenate of ammonia is produced. Thus in every case, where humic acid can be formed from bodies by nitric acid, apocrenate of ammonia is the final product. For instance, phloridzine is converted into phloretine and grape sugar by diluted nitric acid; this grape sugar again into humic acid, and the humic acid into apocrenic acid,—all by the same nitric acid. Thus phloridzine, when acted upon by nitric acid, gives apocrenic acid, though always in combination with ammonia, as represented by the formula :—

$$C^{48}\,H^{12}\,O^{24} + N\,H^{3} + 2\,H\,O$$

This is the composition of a compound produced by the action of nitric acid upon humic acid from sugar, from soil, and from turf, and dried at 284° Fahr., and which is thus an apocrenate of ammonia. The same substance, if saturated with ammonia, and dried at 248° Fahr., gave

$$C^{48}\,H^{12}\,O^{24} + 3\,N\,H^{3},\ 3\ Aq.$$

And again, a lead-salt, from neutral acetate of lead and a solution of neutral apocrenate of ammonia, dried at 230° Fahr., gave

$$C^{48}\,H^{12}\,O^{24} + N\,H^{4}\,O + 4\,Pb\,O,\ Aq.$$

It is probable, that the last atom of water might be separated

---

Crenate of ammonia, from another cultivated soil, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	45.77	24	45.53
H	5.35	15½	5.11
N	1.94	½	2.20
O	46.94	18	47.16

$$= 2\,(C^{24}\,H^{12}\,O^{16} + H\,O) + N\,H^{3} + H\,O$$

Crenic acid, from a third kind of arable soil, at 284° Fahr.

	Found.	Atoms.	Calculated.
C	46.87	24	46.78
H	4.97	15	4.77
O	48.16	19	48.45

$$= C^{24}\,H^{12}\,O^{16} + 3\,H\,O$$

The crenates and apocrenates, separated from the cultivated soils as well as the crenic acid, the analyses of which are above given, were all in combination with oxide of copper.

at a higher temperature, but, as the salt is readily decomposed and difficult to be dried, this has not been attempted.

We are, therefore, entitled to call the artificial acid a five-basic one. Like the ulmic, humic, and geïc acids, it belongs to the gelatinizing substances, which, like alumina, exhibit different characters in relation to water, bases and acids, according to the difference of circumstances ;—by which property it is enabled, both to absorb a large proportion of water, and to combine with several bases at once. Nay, it is by this five-basic character that insoluble apocrenates—for instance that of oxide of iron—are rendered soluble in water, by being combined into double salts with soluble apocrenates. In virtue of this property, plants may, along with the four organic elements, either be supplied with several bases at once, or these bases may be alternately exchanged, according as the proportion of a more powerful base in the soil is less, and that of a more feeble one, temporarily greater. There may exist, for example, apocrenates represented by the following formulae, which, being all soluble in water, and existing in the soil, can be supplied as food to plants :—

$C^{48} H^{12} O^{24} + 5\,N H^4 O$
$C^{48} H^{12} O^{24} + 4\,N H^4 O + K O$
$C^{48} H^{12} O^{24} + 3\,N H^4 O + K O + Ca O$
$C^{48} H^{12} O^{24} + 2\,N H^4 O + K O + Ca O + Mg O$
$C^{48} H^{12} O^{24} + N H^4 O + K O + Ca O + Mg O + Fe O$

For this reason, the apocrenic acid is of inestimable value to plants, and in the series of substances which are useful to them, it deserves, no doubt, a much higher rank than the humic class of acids.

It is from the latter, that the apocrenic acid is produced in the soil. We have seen, that when nitric acid acts upon humic acid, apocrenate of ammonia is produced. This action takes place in such a way, that, when nitric acid is poured upon humic, ulmic, or geïc acid, in whatever way these acids may be prepared, formic and oxalic acids are simultaneously produced. From two equiv. of humic acid, for example, and $N O^{45}$ (one of nitrogen, and 45 of oxygen) derived from nitric acid, are formed,—

	C^{80}	H^{30}	N	O^{75}
1 equiv. of apocrenic acid, ...	C^{48}	H^{12}		O^{24}
1 equiv. of ammonia, ...		H^{3}	N	
12 equiv. of formic acid, ...	C^{24}	H^{12}		O^{36}
4 equiv. of oxalic acid, ...	C^{8}			O^{12}
3 equiv. of water, ...		H^{3}		O^{3}
	C^{80}	H^{30}	N	O^{75}

During this action of nitric acid on humic acid, which takes place with much vehemence, deutoxide of nitrogen is abundantly given off.

It is thus that apocrenic acid is formed in the soil, but of course accompanied by the production of carbonic acid, instead of either oxalic or formic acid. The ammonia of the soil,—produced in it from the atmospheric air it has absorbed,—may, by the influence of decaying organic substances and water, be converted into nitric acid, and no doubt is so when the bases required for nitrification are present. Saltpetre was long extracted from the soil exclusively, as in many places of Egypt, India, &c. By the oxygen of the atmospheric air contained in the soil, the hydrogen and nitrogen of the ammonia—produced from the constituents of the air—are oxidized, water and nitric acid being the products. But this nitric acid, as soon as it is formed, meets with a substance in the soil—humic acid or humin—which, by its influence, is converted into apocrenate of ammonia, and, at the same time, produces carbonic acid, instead of formic and oxalic acids. This change of humic acid into apocrenic acid takes place in minute quantities, as is the case with the formation of ammonia which precedes it. Thus, to form 1 equivalent of apocrenic acid, there are required 2 equiv. of humic acid, 1 equiv. of ammonia, and 76 equiv. of oxygen, thus:—

	C^{80}	H^{33}	N	O^{106}
1 equiv. of apocrenic acid, ...	C^{48}	H^{12}		O^{24}
1 equiv. of ammonia, ...		H^{3}	N	
32 equiv. of carbonic acid, ...	C^{32}			O^{64}
18 equiv. of water, ...		H^{18}		O^{18}
	C^{80}	H^{33}	N	O^{106}

In this production of apocrenic acid, the ammonia from the humate of ammonia is only transferred to the apocrenic acid, but it performs an intermediate part, namely, the fixing of oxygen. Through the tendency of ammonia to form nitric acid, the oxygen of the atmospheric air contained in the soil is combined with the constituents of the humic acid, the ammonia itself remaining unchanged, neither leaving the soil, nor being oxidized into nitric acid. If there be not an abundance of organic matter, and if the air be moist, and lime, magnesia, or potash, be present, ammonia is first produced, and afterwards nitric acid. If, on the contrary, instead of these bases, organic substances are in excess, humic acid is formed by their decay; at the same time, ammonia is produced from the nitrogen of the atmosphere; and, finally, apocrenate of ammonia, carbonic acid, and water.

This formation of apocrenate of ammonia by the oxidation of humate of ammonia, is continually going on in the soil during the warmth of summer (except on the very surface, which is directly exposed to the air). Each minute portion produced can be taken up by the roots of plants, in the form of double apocrenates of ammonia and various fixed bases, provided there be a sufficient supply of water at hand; and whilst in this way the soil loses its apocrenates, a new portion of apocrenate of ammonia is formed from the humic acid or humin, which is present in large excess.

Thus we may call the production of apocrenic acid, in one respect, an organic nitrification.*

We have hitherto represented the apocrenic acid as formed directly from the humic acid. But the existence, in the soil, of a substance which is composed of $C^{40}\,H^{12}\,O^{14}$, instead of $C^{40}\,H^{12}\,O^{12}$—namely, the geïc acid—renders it probable that the apocrenic acid derives its origin, not from humic, but from geïc acid, the several acid substances succeeding each other in this order,—ulmic, humic, geïc, apocrenic acid. This series is concluded by a fifth important substance, a final product of the oxidation of organic substances before they are entirely changed into carbonic acid and water, namely, *crenic acid*.

The composition of this acid, as already mentioned, is

* For the facts upon which these propositions are founded, see Scheik. Onderz., vol. ii.

$C^{24} H^{12} O^{16}$. It also is combined with ammonia in the soil, and forms double salts which are soluble in water.* These exist, along with the apocrenates, in all kinds of water, which have been in contact with organic substances in the soil. They were first found by Berzelius, in spring-water; they exist also in the water of ditches, marshes, and bogs. The crenate of ammonia, when combined with oxide of copper, contains also a variable per centage of water and ammonia, like the apocrenates of ammonia obtained in the above-mentioned analyses of different soils (page 136). The specimens analysed gave, after subtraction of the oxide of copper :—

$$C^{24} H^{12} O^{16} + N H^4 O + Aq.$$
$$2 (C^{24} H^{12} O^{16}) + N H^4 O + 2 Aq.$$

According to the atomic weight of crenate of ammonia, as determined by Berzelius, the crenic acid is four-basic. Of this acid, therefore, the following series of combinations may exist in the soil :—

$$C^{24} H^{12} O^{16} + 4 N H^4 O$$
$$C^{24} H^{12} O^{16} + 3 N H^4 O + K O$$
$$C^{24} H^{12} O^{16} + 2 N H^4 O + K O + Ca O$$
$$C^{24} H^{12} O^{16} + N H^4 O + K O + Ca O + Mg O$$

Just as in the apocrenates, there will be in these salts a larger portion of crenate of ammonia, according as the quantity of ammonia in the soil is increased. Now, during the warmth of summer, the moist air, contained in the soil, has a continual tendency to form ammonia. Among the bases of the crenates, therefore, the ammonia will be the most prevalent, just as in the case of the apocrenates.

Berzelius has stated, that apocrenic acid is easily formed from crenic acid, by the action of atmospheric air. Oxygen is absorbed, and nothing but water produced :—

	C	H	O
2 equiv. of crenic acid, ...	48	24	32
1 equiv. of apocrenic acid, ...	48	12	24
Difference, ...		12	8
Add 4 of oxygen from the air,			4
12 of water produced, ...		12	12

* See the note at page 162.

But Berzelius has remarked that, on the other hand, apocrenic acid can be converted into crenic acid by nitric acid:—

	C	H	O
1 equiv. of apocrenic acid, ...	48	12	24
1 equiv. of crenic acid, ...	24	12	16
Difference, ...	24		8
Oxygen from the nitric acid, ...			40
24 equiv. of carbonic acid, ...	24		48

By the continual tendency to nitrification in the soil, therefore, apocrenic acid must always be converted into crenic acid, the series of ulmic, humic, geïc, and apocrenic acids, thus terminating with crenic acid. In the upper layer of the soil, however, where the air is not inclosed, and consequently no tendency to nitrification exists, crenic acid must conversely be changed into apocrenic acid.

All that we have said here, regarding the formation of the apocrenic and crenic acids from the ulmic, humic, and geïc acids, through the influence of warmth and moist inclosed air, applies also to charcoal, and generally to all coaly substances. For we know that from charcoal apocrenic acid is formed by the action of nitric acid. We need not repeat that charcoal must, of necessity, promote the growth of plants, because, through the organic nitrification already described, which takes place in moist charcoal containing atmospheric air, first, ammonia is formed, and then, as this becomes oxidized, nitric acid and water. By this acid, again, the charcoal is changed into apocrenic acid and ammonia, and this apocrenic acid, by the progressive organic nitrification, is converted into crenic acid. Thus it is not at all singular, that by means of moist charcoal mixed with wood-ashes, the growth of plants should be promoted.

This brief exposition of the peculiar changes which take place in the soil, may now be brought to a close. They are sufficiently plain of themselves. One point, however, remains to be noticed. The ulmic acid is produced from organic substances—for instance, from those which are neutral, such as

cellulose (woody fibre), starch, &c.—carbonic acid being produced at the same time. Thus if

	C	H	O
From 2 equiv. of cellulose, ...	48	42	42
We take 1 equiv. of ulmic acid,	40	14	12
8 equiv. of carbonic acid, ...	8		16
14 equiv. of water, ...		14	14
Or the sum, ...	48	28	42

—then, of the 42 equivalents of hydrogen, 14 are still wanting, which, during the rotting or the slow decay of wood, must be otherwise worked up. In fact, this hydrogen, in the nascent state, promotes the production of ammonia from the nitrogen of the air. Such is the case, also, in the formation of apocrenic and crenic acids. For instance, if

	C	H	O
From 2 equiv. of humic acid, ...	80	24	24
We take 1 equiv. of apocrenic acid, ...	48	12	24
There remain, ...	32	12	

So that, by the absorption of 64 equivalents of oxygen from the atmosphere, all the carbon would be converted into carbonic acid, and again 12 equivalents of hydrogen would be left behind.

It deserves particular notice, that hydrogen is always liberated whenever those substances which are the most generally diffused in the vegetable kingdom, are changed into constituents of the soil—that is, when cellulose, starch, gum, sugar, &c., are in a state of decay. First, these substances are converted into ulmic acid, and that again becomes humic acid; from this, geïc acid is formed, which again produces apocrenic acid, and from that, finally, crenic acid is derived. This whole series of transformations must be passed through, before the organic substance is converted into carbonic acid and water. The whole process consists in an oxidation, and so may be called a slow combustion. It is evident, from the composition of the five substances mentioned, that during the forma-

tion of humus a new quantity of oxygen is continually fixed. Thus—

Ulmin and ulmic acid, ...	$C^{40}\ H^{14}\ O^{12}$
Oxygen from the air, ...	O^{2}
Form, ...	$C^{40}\ H^{14}\ O^{14}$

Which is equal to—

Humin and humic acid, ...	$C^{40}\ H^{12}\ O^{12}$
2 equiv. of water, ...	$H^{2}\ O^{2}$
	$C^{40}\ H^{14}\ O^{14}$

Again,—

Humin and humic acid, ...	$C^{40}\ H^{12}\ O^{12}$
With oxygen from the air, ...	O^{2}
Form geïc acid, ...	$C^{40}\ H^{12}\ O^{14}$

Or, let us suppose that cellulose is at once converted into a portion of each of the three acids—the ulmic, the apocrenic, and the crenic acids. Then we have—

Ulmic acid, ...	$C^{40}\ H^{14}\ O^{12}$
Apocrenic acid, ...	$C^{48}\ H^{12}\ O^{24}$
Crenic acid, ...	$C^{24}\ H^{12}\ O^{16}$
Making together, ...	$C^{112}\ H^{38}\ O^{52}$

When these three acids are thus produced from cellulose—carbonic acid and water being formed at the same time—thirty of hydrogen (H^{30}) remain behind. Thus—

5 equiv. of cellulose, ...	$C^{120}\ H^{105}\ O^{105}$
Ulmic, apocrenic and crenic acids as above,	$C^{112}\ H^{38}\ O^{52}$
37 equiv. of water, ...	$H^{37}\ O^{37}$
8 equiv. of carbonic acid, ...	$C^{8}\ O^{16}$
30 equiv. of hydrogen, ...	H^{30}
	$C^{120}\ H^{105}\ O^{105}$

Thus, in whatever way we suppose the decomposition of cellulose, starch, gum, sugar, &c., to take place, there is always an excess of hydrogen. This may be shown by two additional examples:—

First, suppose ulmic acid to be changed into crenic acid. Then—

Ulmic acid, ...	$C^{40}H^{14}O^{12}$
With 36 equiv. of oxygen from the air, ...	O^{36}
Make together, ...	$C^{40}H^{14}O^{48}$

Which are equal to—

Crenic acid, ...	$C^{24}H^{12}O^{16}$
16 equiv. of carbonic acid, ...	$C^{16}O^{32}$
2 equiv. of hydrogen, ...	H^{2}
	$C^{40}H^{14}O^{48}$

Second, suppose all the carbon from ulmic, apocrenic, and crenic acids to be oxidized by the oxygen of the air, then we have—

Ulmic acid, ...	$C^{40}H^{14}O^{12}$
Apocrenic acid, ...	$C^{48}H^{12}O^{24}$
Crenic acid, ...	$C^{24}H^{12}O^{16}$
	$C^{112}H^{38}O^{52}$
Add to this 172 equiv. of oxygen from the air, ...	O^{172}
	$C^{112}H^{38}O^{224}$
And deduct 112 equiv. of carbonic acid, which are formed,	$C^{112}O^{224}$
And there remain 38 equiv. of hydrogen, ...	H^{38}

This hydrogen, when liberated, is, no doubt, to a great extent, oxidized into water; but, while becoming free, it promotes the formation of ammonia from the nitrogen of the air, and this again of saltpetre. In the same way, as we have already seen, the repeated formation of apocrenic and crenic acid in the soil is effected.

From what has been stated, the observation of de Saussure, that the soil yields just as much carbonic acid, as it absorbs

of oxygen—cannot possibly be accurate; for the existence of ulmic, apocrenic, and crenic acids in the soil, contradicts his theory.

We now approach, in its natural order, the important question, whether plants take organic substances from the soil—as crenates and apocrenates, gëates, humates, and ulmates, for example—or whether they live only on carbonic acid, ammonia, and water; or whether they do both. It were useless to enter here into a prolix exposition of what is known on this subject, since it more properly belongs to the chapter *on the nourishment of plants.* We shall here, therefore, advert only to what is supplied to plants from the atmosphere and from the soil, in addition to the substances we have hitherto spoken of, and which are never wanting in an arable soil. We intend to show what, besides the substances already mentioned, they may absorb; and inquire afterwards what they do really absorb, and in what way the component parts of plants are thence built up.

The black layer of soil, as regards its organic portion, is composed of insoluble ulmin and humin, of soluble ulmates, humates, gëates, apocrenates and crenates of ammonia, potash, soda, lime, magnesia, and oxide of iron. Till recently the opinion prevailed, that the humic acid was the especial feeding substance of plants;—that, in certain circumstances, it could become soluble in water; and that this solution of humic acid was absorbed by the roots of plants, new substances being formed from it in the plant itself: for this humic acid is composed of carbon, hydrogen, and oxygen, three of the four elements of which all the parts of vegetables and animals are built up. The fourth element, namely, the nitrogen, caused some difficulty. It was not found in the humic acid, prepared from sugar, and it was overlooked in the acid, which exists in the soil (Sprengel). Thus, an essential part of what is required to form organic substances, was still wanting. Boussingault thought that this fourth element, the nitrogen, was condensed from the atmosphere in the soil; he did not, however, indicate how this takes place.

The ancient idea was, that plants take all their food from

the soil. But this was contradicted by a great many observations. First, many plants live in the atmosphere only; of others, the roots are fixed in the soil, but in such a soil as contains only a small quantity of soluble, and even of organic substances—at all events, much too little to supply nourishment to the plants. It is a known fact, that from good clay soils, which contain only a small proportion of organic substances, thousands of pounds of vegetable produce are reaped every year, although few or no organic substances—in the state of manures—be added to these soils. Are the organic constituents of such a soil inexhaustible? The absurdity of this supposition is palpable. The example of our heath-lands, however, is still more striking. A barren sandy soil, covered with a thin layer of organic substances, is ploughed and planted with pines. Nothing more is needed to make such a soil produce, in the course of time, a thick layer of organic substances, though nothing be laid on it from without. Here, therefore, the plants supply organic substances to the soil, that is, they do just the reverse of what the old theory supposes.

If we consider, besides, that the luxuriant vine grows in a handful of soil, which is sometimes artificially laid down in the corners of the rocks; that many Cacti adhere to rocks, living where no soil is found at all; that many Orchidea are really air-plants, and do not require soil at all, but only an atmosphere which is suited to their nature; that in the natural forests, whence thousands of pounds are every year carried off for use, without any thing being returned, the quantity of organic substances, with which the soil is covered, is continually increasing; that not a few farms can wholly supply their own wants, without laying anything on the soil, except the products of the farm itself, though immense quantities of beef, grain, fruit, &c., are yearly carried off, and that such a farm continues to be among the most productive; that our pastures are yearly deprived of immense quantities of organic substances through our herbivorous stock, which carry off from the land immense quantities of beef and mutton, exceeding greatly the quantity of organic substances which they

receive; that from meadows which are never supplied with an organic substance, immense quantities of hay are yearly carried off; finally, that the naked rock, where no soil is to be found at all, is, without any artificial aid, covered first with mosses, and afterwards with larger and longer plants, till at last it is adorned with the most luxuriant woods, and covered with a continually increasing layer of black soil *(Linnæus, de Telluris Habitabilis Incremento)*; if we add further the numerous other examples, which will occur to every one;—then the conclusion is incontrovertible, that it is by no means indispensable that the soil should contain *all* the substances which nourish plants.

But since plants require to be fixed in the soil, and have roots for that purpose, are we entitled to suppose that the soil is not indispensable to their nourishment? This can by no means be asserted; all that we maintain is, that all the materials upon which, in certain circumstances, plants may thrive, are not continually present in the soil, and do not require to be so; that these substances need not constitute an essential part of the soil.

In order, then, to conceive by what means plants may live, which have either no organic substances, or no sufficient supply of these to live upon, it must be borne in mind that they receive nourishing substances, if not *from*, yet certainly *through*, the soil.

By the rain-water, carbonic acid is carried down into the soil, which is already thoroughly penetrated by the atmospheric air, and contains condensed ammonia besides. Thus the four organic substances are at hand in the soil. The water, atmospheric air, ammonia, and carbonic acid, supply to the small roots of plants four primary materials, from which the plant may prepare all its organic parts. Here, therefore, we see food supplied to the roots of plants *through* the soil, but *from* the atmosphere; and we can conceive how a soil may be *poor* in organic substances, and yet *rich* in plants.

When the soil really contains organic substances, the plants will thrive more luxuriantly the more these substances are enabled, by the presence of water and atmospheric air, to sup-

ply carbonic acid and ammonia, which are the main requisites. Here we see the vegetable kingdom appearing in a form peculiarly its own. The leaves which fall every year are thrown upon the ground, and after a time are withdrawn from sight. If in contact with a moist atmosphere, they gradually turn brown, decay, and form a powdery dark-coloured substance;—they putrefy, and as this process goes on, they give off a large portion of carbonic acid, which is diffused through the atmosphere, to be taken up by other plants. The brown powdery residue of the putrefied leaves is ulmin and ulmic acid, and of itself is not fit to be taken up by plants in such a quantity as is requisite for their nourishment.

Finally, the putrefying animal portions produce ammonia, and, at the same time, carbonic acid; and during their putrefaction, yield a continually increasing quantity of these. Hence the reason, why the arable soil is beneficial, nay, indispensable to the greater part of plants; hence also the utility of animal and vegetable manures, which enter the roots of plants, not in the form in which they are added to the soil, but in a state of either partial or of entire decomposition, and so in the form of carbonic acid and ammonia. Hence the reason also, why soils, which contain either few or no organic substances, can yet enable plants to live and thrive, because the atmospheric air carried in by the rain-water can introduce into the soil, though to a smaller extent, the same substances, which in arable land can be produced from humic acid and manures.

Though from all these incontrovertible facts, so beautifully connected together by Liebig, we have ascertained, that carbonic acid, water, and ammonia, carried down from the atmosphere into the earth's crust and to the roots of plants, are a very healthy nourishment for many of them—we are not thereby precluded from asserting, that the ulmates, humates, and geates in the soil, which are soluble in water, as well as the crenates and apocrenates, can also be taken up by the roots of plants; nay that, to a great many, they are absolutely indispensable. We shall return to this subject when treating of the nourishment of plants. Here we would only mention that

some plants, for instance the mosses, which grow upon naked rocks, are really fed *exclusively* by means of the constituents of the atmosphere, carried down into the soil ;—which is, *more or less*, the case with all other plants ;—this fact being as incontrovertible, as that very few plants only can live on carbonic acid, water, and ammonia alone, and that by far the greater number must find organic matters in the soil, to live and thrive upon. A simple glance at the practice of the horticulturist establishes this truth in the clearest manner.*

We have, therefore, now become acquainted with the atmosphere as an important, though not the exclusive, source of nourishment to the existing races of plants.

The service performed by the inorganic substances of the earth's surface must differ, according as they supply nourish-

* Among the facts mentioned by Liebig, to demonstrate that carbonic acid, water, and ammonia, do in truth exclusively supply nourishment to plants, are those relating to their culture in powdered charcoal. Having already (p. 168), investigated the value of this fact, I shall here add only this further illustration :—

Professor Numan informs me of peculiarities with regard to this point, which well deserve to be stated.

Rye, oats, buck-wheat, and turnips, were sown in dry sand, contained in pots, the first three on the 21st of June, the turnips on the 29th of July. The uppermost layer was mixed with some coarse charcoal powder and peat-ash.

The buck-wheat was full-grown in the beginning of September, blossomed very well, and in the latter part of that month ran to seed, which ripened.

The rye came up at the usual time, namely, 10 or 12 days after sowing. It had a fresh dark-green colour, and reached in September the height of about one span and a half.

The oats also regularly advanced in growth, and had an uncommonly beautiful greenish blue colour. The plants reached the height of 24 inches, and had broad and thick leaves. In the end of September these began to wither. A few stalks ran to seed, which, however, did not attain ripeness.

The turnips also grew very luxuriantly, and are still perfectly green (I saw them in January). They have here and there very good tubers, which, however, would be much larger if the seed had been more thinly sown.

It must be remarked, that from the 15th of August to the 15th of September, but little rain fell, so that the sand in the pots was completely dry, and they all continued to grow luxuriantly, though no water had been supplied to them.

The above seeds, sown in sand of which the upper layer was mixed with charred turf powder, gave almost the same results.

In sand alone, without the addition of charcoal, the seeds germinated well, but the plants remained exceedingly small, and died without producing seed.

ment to plants from the constituents of the atmosphere, or from organic substances in the soil. Their relation to the carbonic acid is not known; neither is it known how they supply ammonia to plants, or how carbonic acid and ammonia are influenced by decaying rocks, wherever these two, together with water, must exclusively constitute the organic nourishment of plants. Carbonate of ammonia, if in contact with the roots of plants, though in a very diluted solution, has always a poisonous effect. It is still unexplained how those plants, which live only on the atmosphere, are fed, and what may be the influence exercised upon plants by the powdery substances in the soil, while supplying this atmospheric food.

As to the organic feeding substances, their relations are not unknown. The bases combine with the acids, and enter into the plants in the state of ulmates, humates, gëates, apocrenates, and crenates. There is, however, among the inorganic substances in the soil, one base entitled to particular notice, namely, alumina. In good arable land, it ought not to be absent. Its use is of importance. It combines with the apocrenic and crenic acids into compounds insoluble in water; and it is, therefore, by this substance that the whole quantity of these acids, present in the soil, is prevented from being washed out by the rains. Sandy soils are especially liable to this disadvantage. The spring waters of our moors are coloured brown by apocrenates; while, in our clay soils, these waters are colourless, and almost free from organic substances, although they are equally penetrated by a layer of humus. These two organic acids are both thrown down from their solutions by recently precipitated alumina. (Berzelius, Lehrbuch, Bd. 8, S. 401, and 410.) The crenic acid can be again set free from its combination with alumina, by ammonia. In small quantities, therefore, it is supplied as food to plants, ammonia being continually produced in the soil. By the alumina (clay), as well as by the other bases in the soil, another important service is performed, namely, that of preventing these two acids from being decomposed into carbonic acid and water, and thus preserving them unchanged, when once

formed in the soil, for a very long period of time, till plants begin to grow, to take them up, and to convert them into food.

In this manner, the decayed rocks again show their close and intimate connexion with organic nature; and we may thus understand how indispensable the dead earth is to every living being which now exists upon it.

NOTE.—*Upon the Organic Acids in the Soil.*

I have been unwilling to interrupt the narrative of the author in this very interesting chapter; or farther to load the pages with notes. I have reserved, therefore, for this place, a few remarks upon the organic acids in the soil. It is now several years since I made, and partly published, the results of an examination of some of these acids, and as these results add something to the facts stated above by Mulder, I shall here briefly explain them.

1° At the bottom or towards the lower part of most of the old and deep peat bogs in Scotland and Ireland, a black compact substance is here and there met with, in which no trace of vegetable fibre is to be observed, and which, when dry, breaks with the fracture and lustre of coal. I have analysed this substance from both Scottish and Irish bogs, and have found it so far to agree with the humic acid of Mulder, as to consist, in its organic part, of carbon and water only. The acid, however, is never in an uncombined state. It always contains a trace of ammonia, with from 2 to 6 or 8 per cent. of alumina or lime alone, or of a mixture of these with oxide of iron.

2° Having received from Lord Willoughby de Eresby a quantity of his compressed peat, prepared from the black soapy-looking peat of his estates in Perthshire, I digested a portion of it in fine powder in weak ammonia. It swelled up very much, became bulky, spongy, and difficult to wash, and gave a dark-brown solution, from which muriatic acid threw down a dark-brown acid. When dried and analysed, the black coaly acid was found to be a *humic* acid, containing carbon and water only. The salt of copper, however, gave me for

the formula of the acid $C^{24} H^{12} O^{12}$. It differs, therefore, in the weight of its equivalent, from any of the humic acids of Mulder.

3° When treated with solutions of caustic potash, or of carbonate of potash, or carbonate of soda, the peat did not swell up as in ammonia, and gave a dark-brown solution, from which muriatic acid threw down a brown flocky precipitate, very different in composition from that yielded by the ammoniacal solutions. When dried, this brown precipitate had the same black coaly aspect as the humic acid already described, but its properties and composition differed considerably.

When heated in the air, it gave off white vapours, and a strong smell of burning peat. By the application of a taper, the vapours took fire and burned with a bright flame. The humic acid obtained by ammonia gave off scarcely a trace of these vapours, and only a faint odour of burning peat. The smell appeared to indicate that the acid extracted by alkaline carbonates, pre-exists in the natural peat—and the white combustible vapours, that it contains more hydrogen than the substance extracted by ammonia.

This was confirmed by the analysis of portions of the acid prepared at various times, and precipitated by different acids. The formula for this acid is $C^{24} H^{14} O^{9}$, agreeing therefore with the ulmic acids of Mulder, in containing an excess of hydrogen, but not being reducible to his ulmic group—the excess of hydrogen being very much greater than in his ulmic acid, and the equivalent containing only 24 of carbon, while that of Mulder contains 40 equivalents of carbon. The difference in the proportions of hydrogen in the two acids, will be most readily seen by comparing the formulæ for the two acids, supposing the equivalent of both to contain forty of carbon (C^{40}):—

	C	H	O
Ulmic acid from Frisian peat (p. 154),	40	17	15
Ulmic acid from Scottish peat, ...	40	23	15
Difference, ...		6	

The acids here described agree with those of Mulder in their tendency to unite with several bases at once, and thus to form compounds soluble in water, containing bases, with which, when alone, they form compounds nearly insoluble in water. They also, even when dry, absorb oxygen and nitrogen from the air, producing ammonia and acids, containing more oxygen than the humic and ulmic acids. The dry acids kept in well-corked bottles, after the lapse of twelve months had absorbed a considerable proportion of the air, and gave to alcohol a soluble salt, containing an organic acid in combination with much ammonia. It is almost impossible, as I have found, to prepare a portion of the acid from peat by means even of caustic potash, which will not give evidence of the presence of ammonia, when burned with oxide of copper: but it is only after a prolonged exposure to the air that it contains enough to give a decidedly dark-coloured solution when boiled in alcohol.

4° It may naturally be asked, how, from the same peat, ammonia and carbonated alkalies extract substances so different in composition? Both acids are soluble alike in both fixed alkaline and in ammoniacal solutions; both, therefore, do not exist ready formed in the peat. From the resemblance of the acid C^{24} H^{14} O^9 to the peat itself in giving off a strong odour of peat when burned, and, at a temperature of 500° or 600° Fahr., white vapours, which condense among other products into a white solid carbo-hydrogen, I believe it to exist ready formed in peat, and that the humic acid C^{24} H^{12} O^{12}, is produced from it.

a. If for the sake of comparison, we represent the two acids by formulæ, in which the number of equivalents of oxygen is the same—we should have

	C	H	O
For the one acid (ulmic),	40	23	15
For the other (humic),	30	15	15
Difference,	10	8	

This difference is equal to two equivalents of a carbo-hydrogen C^5 H^4, which may be supposed to be present in the

acid with excess of hydrogen. If, by a cautiously regulated heat, such a compound could be driven off from it, then the humic acid would be produced. When the acid is dried at too high a temperature, this sometimes takes place to a certain extent, and the proportion of hydrogen is in consequence diminished.

b. Or the acid $C^{24} H^{14} O^9$ may be oxidized by the action of ammonia in the presence of the air. If this takes place directly, then each equivalent must absorb five equivalents of oxygen from the air. Thus,

	C	H	O
To the acid	24	14	9
Add from the air ...			5
And we have	24	14	14

which is equal to $C^{24} H^{11} O^{11} + 3$ H O.

This is what I believe takes place either immediately or ultimately. This opinion is founded on the fact, that, when the acid obtained by means of carbonate of soda and sulphuric acid was dissolved in diluted ammonia, and boiled for a length of time, the solution gradually acquired an *acid* reaction, and threw down from a solution of sulphate of copper an insoluble dark brown compound, the organic part of which was represented by $C^{24} H^{11} O^{11}$—that is, the one acid was changed into the other.

5° On certain parts of the rocky coasts of Cornwall, where caves occur, the surface water is observed to trickle through the granite rock, and gradually to cover the sides of the caves with a deposit of greater or less thickness. This deposit, which was first collected by a Mr. Pigot, has been called Pigotite by mineralogists. It consists of an organic acid, in combination with alumina in proportions which vary considerably in different specimens, showing that, like other acids, it forms with alumina combinations in which different proportions of acid and base are present. Some portions of the Pigotite have the aspect and semi-transparency of resin—being in fact the appearance which gelatinous alumina and numerous gelatinous compounds assume when they are allowed

to dry slowly in the air. The quantity of water present in this native product is therefore in some degree variable, but always large. When dried at 212° Fahr., it loses about 26, at 300° about 32 per cent.

When heated in the air over the lamp, the compound blackens, but the carbon burns away with extreme slowness. When reduced to powder, it dissolves readily in a solution of caustic potash, with the aid of heat, and is thrown down again by muriatic or sulphuric acid, apparently unchanged. The proportion of alumina in the precipitate may be changed by this treatment, but the organic acid itself is not altered in composition. The acid itself is separated from the alumina with extreme difficulty and slowness by caustic ammonia, and by carbonated alkalies. In the silver salt it is represented by the formula $C^{12}\ H^{5}\ O^{8}$, and is tribasic,—this quantity of acid uniting with 3 equivalents of oxide of silver. In the native compound of alumina, the acid is represented by—

	C	H	O	Aq
Native compound,	12	5	8	27
Dried at 212° ...	12	5	8	10
Dried at 300° ...	12	5	8	8

The quantity of alumina present being 4 double equivalents. But, as I have already stated, the water varies. The alumina also varies from 44 to 48 per cent. of the dry salt, and is present, no doubt, in different states of saline combination—perhaps even in the state of *hydrate*. Traces of nitrogen are always observed in the analysis of this salt, showing that, like the other acids formed in the soil, it has a strong tendency to unite with ammonia. That this nitrogen, however, does not form a constituent part of the acid, is shown by the fact, that when dissolved in caustic potash, and precipitated by an acid, the composition of the organic part remains unchanged.

This acid is obviously formed from the decaying vegetable matter of the soil above, with the alumina of which it combines, and from which it is washed by the rains or springs, and descends through the crevices of the rocks into the caves below. The organic matter may not descend in the

form of this acid, but may, as it trickles down the sides of the cavern, undergo a further oxidation, and be converted into this acid. It approaches very closely in composition to the crenic acid, as analysed by Mulder, and may even eventually be shown to be identical. Before Mulder's crenic acid was analysed, I had proposed for this acid the name of Mudesous acid.

6° When the native Mudesite of alumina is treated with nitric acid, red fumes are given off, the Mudesous acid undergoes oxidation, and a new acid—the Mudesic—is formed, which is represented by the same formula as the Mudesous, with the addition of two equivalents of oxygen. Thus—

The Mudesous, ...	$C^{12} H^5 O^8$
The Mudesic, ...	$C^{12} H^5 O^{10}$

There can be little doubt, I think, that this oxidation takes place in nature also, in favourable circumstances; and, therefore, that the Mudesic acid is sometimes formed in the soil.

7° From what is above stated, it appears that, to the acids mentioned by Mulder, several others may be added as occurring in certain circumstances in the soil,—forming successive steps in the series of changes through which vegetable matter passes, on its way from the substance of the living plant to the state of carbonic acid and water, into which it is finally resolved. There are three groups of acid and other compounds, into which the organic substances of the soil may be arranged:—

a. The *humic* class, which may be represented by carbon and water only.

b. The *ulmic* class, in which the hydrogen is in excess; and

c. The *geïc* class, in which the oxygen is in excess.

The acid extracted by ammonia from Scottish peat belongs to the first; that extracted by carbonate of soda, to the second; and the Mudesous and Mudesic acids, to the third. An unwillingness to lengthen this note, prevents me from further expounding this view, which, to the scientific chemist, is perhaps less necessary, as I shall hereafter treat of it more fully in another work.—*J*

CHAPTER VI.

GENERAL ORGANIC SUBSTANCES.

Among the numerous organic bodies, there are some of a complicated character, the composition of which cannot be reduced to the simple form, in which the inorganic binary combinations present themselves.

These so-called complex substances form a peculiar group. They are in a high degree changeable under very different conditions,—easily react on substances externally applied to them—readily produce chemical changes—and are, at the same time, readily altered themselves. They are mutual combinations of certain other compounds, which, though they may be combined together into a state of equilibrium, can easily be removed from that state, in consequence of their complex composition.

It is of such complex bodies that the principal component parts of the organic kingdom consist—bodies well adapted to induce incessant changes of substance, without affecting the form of the whole, and to develope and perpetuate the chief characteristics of vital action.

From these complex substances, others, less complicated, are readily produced, either with or without the influence of an organic whole; and, inversely, from these less complicated, more complex substances may also be produced as circumstances or conditions vary.

If we desire to draw a line of distinction in this respect between the two organic kingdoms, we may affirm that the animal organism has a tendency to produce combinations

with simple, or at least well known, radicals; the organism of plants, on the contrary, to produce complex substances. The former results, art may more easily hope to accomplish than the latter; thus, art is more able to imitate the products of the animal body, than those of the plant.

We have already stated (p. 13) that the peculiar properties of the two organic kingdoms ought to be ascribed, first, to the special character of the four elements, carbon, hydrogen, nitrogen, and oxygen—to which may be added, sulphur, phosphorus, iron, and iodine ;—that special character in virtue of which they are capable of forming an endless series of combinations with each other; and second, to the circumstances in which these elements are placed in the organic kingdom. As we have sufficiently treated of these two subjects in the first chapter, we shall only remark here, with regard to the latter point, that carbonate of ammonia—which salt is isomorphous with carbonate of potash—contains in itself all the four organic elements—the elements of innumerable combinations, that are alternately produced and destroyed in the organic kingdom. This salt, which is called an inorganic body, though it is composed of the four organic elements, contains within itself both the materials and the forces, from which all that is peculiar in the organic kingdoms takes its rise. It shows us, in the clearest manner, where we must look for their special character, and where not.

The fundamental substances—the building materials, as it were—of the organic kingdom, are few in number. Nature is simple in her means,—sublime in her aim,—abundant, yea, one should almost say, prodigal, in the diffusion of her riches. Out of a small number of elements, in which she has deposited, as it were, infinite modifications of the same primary force, she creates a few compound bodies, which may be considered as the foundations of the whole organic kingdom. She makes these act upon each other, and thus causes the production of a variety, which the natural philosopher admires the more, the deeper he penetrates into this inexhaustible treasury.

These fundamental substances, therefore, ought above all

others to be known to us. They are of four kinds, namely, those which are common both to plants and to animals—those which exist in one of them only—those which are present in neither, being, nevertheless, materials of the organic kingdom—and, finally, the so-called inorganic substances which occur in a state of combination with the organic substances.

The third division contains carbonic acid, ammonia, water, atmospheric air, humin and humic acid, ulmin and ulmic acid, geïc acid, crenic acid, and apocrenic acid, of which, altogether, the organic part of our arable soils is constituted. The fourth division contains salts of magnesia, lime, soda, potash, manganese and iron, with phosphoric acid, sulphuric acid, iodine, fluorine, and chlorine, and also silica and alumina,—altogether produced from decayed rocks. All these substances, however, belong to the kingdom of organic nature; since whatever is indispensable to it, ought to be considered as organic. They belong to the necessary principles of the organic kingdom, which cannot even be conceived to exist without them.

The first division contains protein; the second, for plants, dextrine; for animals, gelatine. From dextrine are produced cellular fibre, starch, gum, sugar, and probably also bassorine; from the starch are produced fats and chlorophyle. All these substances are of general importance to the chemical physiology of plants. We shall treat briefly of each of them. As to the animal substances, we shall confine ourselves, in the present chapter, to a view of the protein compounds, the gelatines, and the colouring matter of the blood.

Upon these few compounds are laid the foundations of the animal and vegetable kingdoms. Their number may be even further reduced, for most of them are produced from each other. Together, they are the source of all the organic substances found in plants and animals.

Having treated, in the former chapters, of the atmosphere, of water, and of the component parts of the soil, in connexion with organic nature, we refer, for the properties of the substances contained in the last division, to elementary works upon general chemistry. Here we intend to treat, and that

briefly, of the substances of the first and second division, and especially of their origin. The great variety of substances, produced from them in plants and animals, will find a proper place when we come to consider the functions, through which they are produced.

A. Of the Cellular Substance of Plants.

In all plants there exists a small organ, of most simple form, though employed by Nature for most varied purposes. It is a small filmy sac, a thin membrane, which encloses a small space, which it enables to communicate with the exterior space through invisible pores. These little sacs, or *cells*, are the first and chief organs of plants. A countless multitude of them grouped together, forms not this or that part merely, but the whole bulk of the plant; so that, if every thing, except the cells, be destroyed, the shape and size of the plant are not in the least changed or diminished.

These cells fit closely, and press against each other, and seem thus to form a tissue. A mass of them is called cellular tissue. It is chiefly by means of cells that nature produces plants, their parts and organs; it is chiefly through cells that the innumerable variety of products in the vegetable kingdom comes into existence.

Though the external appearance of one cell may be the same as that of another,—of one cellular tissue as that of another—yet their functions are very different. In investigating the functions of the cells, we investigate the functions of the vegetable kingdom. . For it is the cells exclusively, which perform or continue them, or which produce organs for the purpose of performing peculiar functions. Hence that diversity in the character and shape, the arrangement and properties of the cells in plants—subjects which will never cease to engage the attention of the investigator of nature.

With regard to plants of the most simple structure—as, for instance, some moulds—the whole little plant consists only of a few cells linked together, each of which can of itself exist and grow, that is, produce other cells. Thus each

cell is to be considered as a little plant; as each plant is to be considered as a collection of little plants, united into one whole. It is in this chiefly, that we can perceive not only the use, but also the nature of cells and plants; it is chiefly from this, that we may justly infer, that the most simple form a plant can assume, is that of a single cell (for instance, the genus Protococcus among the Algæ), and that we may justly consider very complicated plants, as being formed from an innumerable multitude of such simple little plants. They are little filmy sacs and laminæ, composed of one or more chemical substances, united together into a small concave globule. In these laminæ, and in this sac-like connexion of the molecules, the most admirable powers are concealed; powers which, from the nature of the substances composing the laminæ, are as multifarious as the modifications which the primary forces of the elements, of which the laminæ are built up, can be made to undergo.

The function of one single series of cells is of one kind only. The same substances, united into little sacs in the same manner, produce only one series of vital phenomena: that is, in the most simple shape, the production of new individuals equal to the primary ones. Difference in form, however, without a great difference in substance, enables these series of cells to perform more functions. This is one of the first and chief laws, visible in organic nature; namely, that the form has as much influence on the character of the phenomena, as the substance of which that form consists. A simple cell, extended to a filmy lamina, would no longer be a producing organ, or perform a function. Therefore, in the combinations of the organic molecules, that is, in bodies composed of carbon, hydrogen, nitrogen, and oxygen, or of three of these elements, there exists, first, a power of forming hollow globules, just as most of the other elements have a tendency to crystallise in symmetrical forms.

But in the second place—and this peculiarity is of the utmost importance to the doctrine of life—the effects of the primary forces, existing in the molecules, have become, by that combination of the elements into concave globules, alto-

gether peculiar. This concave globule is an individual; that is, in the most simple form in which it can possibly exist (in the lowest moulds), it possesses all the powers of the molecules united into one whole, and thus reduced to a state of equilibrium. This state depends not only on the nature of the substances, and of their elements, carbon, hydrogen, and oxygen, or carbon, hydrogen, oxygen, and nitrogen; but also on their form. The state of equilibrium, therefore, could not exist, unless this concave globular form existed. Moreover, this hollow globule possesses the whole of these forces in a state of mutual combination, co-operating for one end; this being a peculiarity which also apparently depends on the globular form.

Since these two ideas are founded on pure observation, we may steadfastly adhere to them, and therefore correctly infer, that in organic nature, besides all the peculiarities existing in the carbon, hydrogen, nitrogen, and oxygen, we must suppose, as a chief consequence of this, a tendency to form membranaceous, concave, spherical little bodies, in which, because of this form, new peculiar properties manifest themselves, which cannot be brought out by other forms. Thus by matter and form, by form and matter, all that we observe in nature is to a great extent determined.

This general conclusion is drawn from the innumerable phenomena we perceive in the organic world—phenomena which differ, whether, on the one hand, the materials are the same, and the forms differ, or, on the other, the materials differ, while the forms are the same.

If, therefore, the vegetable kingdom consisted of one common cellular substance, this being different, however, only as *to the form*, either in various tribes or genera, or species, or parts, or organs of plants; the effects of the same chemical body, of the same cellular substance, must, of necessity, be different for each different form. This has in fact been found to be true. These little individuals, these little cells, become other individuals when different in form, or when connected together in a different manner, though they consist almost of the same substances. The very smallest differences in the

As to the cells, whatever may be their shape, they all consist, when young, of a thin tender film, in which we cannot discover any pores even with the microscope, though fluids pass through it with great facility. For the most part, we cannot distinguish in this membrane any structure at all. Sometimes, however, we may discover in it spiral-like fibres, lying parallel, and in contact with each other. According to Meyen,* all sorts of cells do consist of such spiral-like threads, which in the majority of cases have ceased to be discernible, in consequence of having been early connected together. (See theory of cells below.)

The cell-film is for the most part transparent, colourless in many mono- and di-cotylydenous, coloured in many cryptogamic plants. When coloured in the mono- and di-cotylydoneæ, the tint is due to the presence of other substances, which are either contained in the cells, or have penetrated the substance of the membrane itself. In general it is exceedingly thin, though in this respect differences are perceptible in various plants at different ages, and even in different parts of the same plant. Within the wide original cell-membrane of the greater part of plants, small particles are deposited, by which the thin film is thickened. These particles increase, especially with the age of the plant. They are produced in greatest abundance during the formation of wood, when they are not only closely compressed, but likewise by their great number cause the entire space of the cells to be filled up, so as sometimes to give a considerable degree of hardness to the whole. Thus, while wood is produced, a hard substance is secreted, the presence of which completely changes the function of the cells. For, in the first place, every particle of heterogeneous matter laid down, either against or in the walls of the cell-film, must affect the function of the latter; in the second place, so great a quantity of matter is deposited in the formation of wood, that the fluids are almost entirely prevented from passing through the membranes—to such an extent, indeed, that at last the cells prove almost wholly inactive. But this thickening of the walls of the cell-mem-

* Pflanzen—Physiologie, I. s. 19.

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be $C^{3}H^{2}O^{2}$, harmonizing with the starch series, $C^{12}H^{8}O^{8}$.* From a great many experiments of Payen, however, it would appear, that this formula is not accurate; that the substance which converts cellulose into wood, is composed according to the formula $C^{17\frac{1}{3}}H^{12}O^{10}$, the composition of cellulose itself being $C^{12}H^{10}O^{10}$.

From the experiments of Payen himself, however, and from others made by Fromberg and by von Baumhauer, mentioned below, it appears, that the formula of cellulose is not $C^{12}H^{10}O^{10}$, but $C^{24}H^{21}O^{21}$, agreeing not with starch, but with the soluble inuline.

Pure cellulose is easily obtained from the pith of the elder tree, from very young roots, and from other young parts of plants. From other parts it is prepared, by digesting them, after being minutely divided, with alcohol, ether, diluted potash, hydrochloric acid, and water. In this manner, the starch, gum, fats, resins, vegetable alkalies, salts, sugar,—and at the same time the peculiar woody matter—are separated. The latter has been called, by Payen, *incrusting matter* (matière incrustante). It is, however, deposited not merely against the cellulose, but also between its molecules. The name of incrusting matter is thus, strictly speaking, inapplicable. After the action of these solvents, and especially of the alkali, the cellulose, which was formerly solid and dense, appears in a spongy form.† The following substances, when previously purified in this manner, gave always the same results for the composition of cellulose: namely, the ovula of almonds, of apples, of the Helianthus annuus, the sap of cucumbers, the tissue of the cucumber, the pith of the elder tree, the pith of the Æschynomene paludosa, cotton, the extremities of roots (spongioles), wood sufficiently extracted, the leaves of endive, and of Aylanthus glandulosa, the

* Gay Lussac and Thenard have found in

	Oak-wood.	Beech-wood.	Atoms.	Calculated.
C	52.53	51.45	3	50.18
H	5.69	5.82	2	5.49
O	41.78	42.73	2	44.03

† Annales des Sc. Nat., Mai 1840, 2d Sec. p. 305. The intersection of a cell however, filled with woody matter, shows us several layers.

branes with other solid, and even hard substances, does not take place in the formation of wood alone. Hugo Mohl first observed it even in the parenchymatical cells of the Hoya carnosa, and of the Banisteria auriculata.

The substances, with which the cell-membranes are thus incrusted, are not the same in all the incrusted cells. I shall here therefore state what we at present know upon this subject, and especially in regard to the substance, of which the thin cellular membrane in all plants, without exception, appears to consist.

In all plants, both cellular and vascular, a substance exists which is now called *cellulose*, or the cellular substance of plants. Of this substance the young parts of plants are to a great extent built up. In the pith it exists in a tolerably pure state, but in the wood it is always more and more combined with another substance of a different composition. It is a substance from which, besides the cells, other component parts of plants can be produced. This point, however, has not yet been sufficiently investigated with the microscope. As the elementary principle of the cells of plants, it must be considered, at all events, as an important substance in the vegetable kingdom; it, therefore, deserves the first and chief place, being the building material, as it were, of the organic kingdom.

This cellular substance is to be procured from all the parts of plants, without exception, simply by separating every other substance by means of solvents. It is thus very easily prepared. As it exists in the young parts of plants, it is one of those substances, which are first prepared from their food. It can originate only from a substance soluble in water, and it is, no doubt, dextrine from which it is produced, and which must therefore precede its formation. But being once produced in any part of a plant, it continues to exist there either in whole or in part. It is present, therefore, in organs of every age.

It was formerly assumed, that wood, if free from all heterogeneous mixtures, had a constant composition, the substance of which it consisted being called *lignine*. Gay Lussac and Thenard, as also Prout, found the formula for its composition to

be $C^3 H^2 O^2$, harmonizing with the starch series, $C^{12} H^8 O^8$.* From a great many experiments of Payen, however, it would appear, that this formula is not accurate; that the substance which converts cellulose into wood, is composed according to the formula $C^{17\frac{1}{4}} H^{12} O^{10}$, the composition of cellulose itself being $C^{12} H^{10} O^{10}$.

From the experiments of Payen himself, however, and from others made by Fromberg and by von Baumhauer, mentioned below, it appears, that the formula of cellulose is not $C^{12} H^{10} O^{10}$, but $C^{24} H^{21} O^{21}$, agreeing not with starch, but with the soluble inuline.

Pure cellulose is easily obtained from the pith of the elder tree, from very young roots, and from other young parts of plants. From other parts it is prepared, by digesting them, after being minutely divided, with alcohol, ether, diluted potash, hydrochloric acid, and water. In this manner, the starch, gum, fats, resins, vegetable alkalies, salts, sugar,—and at the same time the peculiar woody matter—are separated. The latter has been called, by Payen, *incrusting matter* (matière incrustante). It is, however, deposited not merely against the cellulose, but also between its molecules. The name of incrusting matter is thus, strictly speaking, inapplicable. After the action of these solvents, and especially of the alkali, the cellulose, which was formerly solid and dense, appears in a spongy form.† The following substances, when previously purified in this manner, gave always the same results for the composition of cellulose: namely, the ovula of almonds, of apples, of the Helianthus annuus, the sap of cucumbers, the tissue of the cucumber, the pith of the elder tree, the pith of the Æschynomene paludosa, cotton, the extremities of roots (spongioles), wood sufficiently extracted, the leaves of endive, and of Aylanthus glandulosa, the

* Gay Lussac and Thenard have found in

	Oak-wood.	Beech-wood.	Atoms.	Calculated
C	52.53	51.45	3	50.48
H	5.69	5.82	2	5.49
O	41.78	42.73	2	44.03

† Annales des Sc. Nat., Mai 1840, 2d Sec. p. 305. The intersection of a cell however, filled with woody matter, shows us several layers.

tracheæ of the Musa sapientum, films from the pith of oak trees, cellulose from cow dung (the cow being fed with meadow grass), the internal tissue of the leaves of Agave Americana, cotton from the seed of the Virginian poplar, vegetable membranes, the skeleton of a wasp's nest, wood from Coniferæ (duly extracted), the Perisperm of the Phytelephas, extracted Lichen, Conferva rivularis, Agaricus edulis, Boletus igniarius, membranes of the Chara, and of the Conferva oscillatoria.

From all these substances the cellulose, after being extracted by means of the above solvents, gave, when analysed, no other result, than one approximating to $C^{24}\ H^{21}\ O^{21}$. So that we may state, as a fact, that the proper tissue of all plants, which have been previously exposed to the influence of these solvents, leaves a substance which is identical for all of them,—a substance, which contains carbon and the elements of water; that this substance is isomeric with inuline; that it may, therefore, be very easily changed into starch and sugar; and that in its turn it may possibly be produced, just as easily, from dextrin—the change in this instance consisting only in the loss or addition of water.* Such a change appeared to

* Payen (Annales des Sciences Naturelles, Serie 2d, Tome II. Botanique, 1839, p. 21), first obtained a knowledge of cellulose, by investigating the tissue of plants in its growing state, for which purpose he used the gelatinous substance, contained in the unfecundated ovula of the Amygdalus sativa. He obtained another series of more tender membranes, by carefully cutting off the extremities of the radicles and their fibres from some woody and herbaceous plants; and also by examining the young pith of elder trees; finally, by the analysis of the pith of Æschynomene paludosa and of cotton. He purified these substances (though he does not mention how), and dried them *in vacuo*, at 302°–356° Fahr. He thus found the composition of these substances to be:

	Ovula of Almonds.	Of Apples.	Of Helianthus Annuus.	Sap of Cucumbers.
C	43.57	44.7	44.1	43.90
H	6.11	6.0	6.2	6.22
O	50.32	49.3	49.7	49.88

	Tissue of Cucumbers.	Pith of the Elder Tree.	Pith of the Æsch. Paludosa.		
C	43.80	43.37	43.2	43.57	43.4
H	6.11	6.04	6.5	6.20	6.3
O	50.10	50.59	50.3	50.23	50.3

Payen really possible. It is, in fact, an important peculiarity, confirmed by von Baumhauer for the Phytelephas. By sulphuric acid, the cellulose is changed into dextrin ; a change, caused

	Cotton.		Spongioles of young roots.
C	45.00	44.35	43.00
H	6.22	6.14	6.18
O	48.78	49.51	50.82

From these results, Payen drew the conclusion, that the peculiar tissue of plants is not lignine, and that the latter is acted upon by potash, soda, and nitric acid, while the former is not.

By the analysis of wood he obtained from

	Oak,		Beech,	
	In its natural state.	Treated with soda.	In its natural state.	Treated with soda.
C	54.44	49.68	54.35	49.40
H	6.24	6.02	6.25	6.13
O	39.32	44.30	39.50	44.47

	Populus tremula,		
	Treated with soda.	Washed twice.	Herminiera elaphroxylon in its natural state.
C	48.00	47.71	47.18
H	6.44	6.42	5.94
O	45.56	45.87	46.88

It follows, from the above analyses, that the several kinds of wood, the more lignine they contain, give the more carbon, for the maxima come nearest to the results of the analysis of lignine, made by Gay Lussac and Thenard.

Wood from oak and beech, reduced to fine powder, was left by Payen for thirty hours in a large quantity of strong nitric acid ; and thus the incrusting matter was separated. The undissolved, elementary tissue, washed first with soda and then with water, and dried at 320° Fahr., gave

C	43.85
H	5.86
O	50.29

that is, a composition approximating very nearly to that of the original tissue above mentioned.

Further, Payen has given the composition of the incrusting matter, though without mentioning any particulars. This he found to be represented by $C^{?} H^{36} O^{?}$, the formula of the cellulose being, according to him, $= C^{12} H^{10} O^{10}$.

The incrusting matter consists in 100 parts of

C	53.76
H	6.00
O	40 24

briefly, of the substances of the first and second division, and especially of their origin. The great variety of substances, produced from them in plants and animals, will find a proper place when we come to consider the functions, through which they are produced.

A. Of the Cellular Substance of Plants.

In all plants there exists a small organ, of most simple form, though employed by Nature for most varied purposes. It is a small filmy sac, a thin membrane, which encloses a small space, which it enables to communicate with the exterior space through invisible pores. These little sacs, or *cells*, are the first and chief organs of plants. A countless multitude of them grouped together, forms not this or that part merely, but the whole bulk of the plant; so that, if every thing, except the cells, be destroyed, the shape and size of the plant are not in the least changed or diminished.

These cells fit closely, and press against each other, and seem thus to form a tissue. A mass of them is called cellular tissue. It is chiefly by means of cells that nature produces plants, their parts and organs; it is chiefly through cells that the innumerable variety of products in the vegetable kingdom comes into existence.

Though the external appearance of one cell may be the same as that of another,—of one cellular tissue as that of another—yet their functions are very different. In investigating the functions of the cells, we investigate the functions of the vegetable kingdom. For it is the cells exclusively, which perform or continue them, or which produce organs for the purpose of performing peculiar functions. Hence that diversity in the character and shape, the arrangement and properties of the cells in plants—subjects which will never cease to engage the attention of the investigator of nature.

With regard to plants of the most simple structure—as, for instance, some moulds—the whole little plant consists only of a few cells linked together, each of which can of itself exist and grow, that is, produce other cells. Thus each

cell is to be considered as a little plant; as each plant is to be considered as a collection of little plants, united into one whole. It is in this chiefly, that we can perceive not only the use, but also the nature of cells and plants; it is chiefly from this, that we may justly infer, that the most simple form a plant can assume, is that of a single cell (for instance, the genus Protococcus among the Algæ), and that we may justly consider very complicated plants, as being formed from an innumerable multitude of such simple little plants. They are little filmy sacs and laminæ, composed of one or more chemical substances, united together into a small concave globule. In these laminæ, and in this sac-like connexion of the molecules, the most admirable powers are concealed; powers which, from the nature of the substances composing the laminæ, are as multifarious as the modifications which the primary forces of the elements, of which the laminæ are built up, can be made to undergo.

The function of one single series of cells is of one kind only. The same substances, united into little sacs in the same manner, produce only one series of vital phenomena: that is, in the most simple shape, the production of new individuals equal to the primary ones. Difference in form, however, without a great difference in substance, enables these series of cells to perform more functions. This is one of the first and chief laws, visible in organic nature; namely, that the form has as much influence on the character of the phenomena, as the substance of which that form consists. A simple cell, extended to a filmy lamina, would no longer be a producing organ, or perform a function. Therefore, in the combinations of the organic molecules, that is, in bodies composed of carbon, hydrogen, nitrogen, and oxygen, or of three of these elements, there exists, first, a power of forming hollow globules, just as most of the other elements have a tendency to crystallise in symmetrical forms.

But in the second place—and this peculiarity is of the utmost importance to the doctrine of life—the effects of the primary forces, existing in the molecules, have become, by that combination of the elements into concave globules, alto-

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gether peculiar. This concave globule is an individual; that is, in the most simple form in which it can possibly exist (in the lowest moulds), it possesses all the powers of the molecules united into one whole, and thus reduced to a state of equilibrium. This state depends not only on the nature of the substances, and of their elements, carbon, hydrogen, and oxygen, or carbon, hydrogen, oxygen, and nitrogen; but also on their form. The state of equilibrium, therefore, could not exist, unless this concave globular form existed. Moreover, this hollow globule possesses the whole of these forces in a state of mutual combination, co-operating for one end; this being a peculiarity which also apparently depends on the globular form.

Since these two ideas are founded on pure observation, we may steadfastly adhere to them, and therefore correctly infer, that in organic nature, besides all the peculiarities existing in the carbon, hydrogen, nitrogen, and oxygen, we must suppose, as a chief consequence of this, a tendency to form membranaceous, concave, spherical little bodies, in which, because of this form, new peculiar properties manifest themselves, which cannot be brought out by other forms. Thus by matter and form, by form and matter, all that we observe in nature is to a great extent determined.

This general conclusion is drawn from the innumerable phenomena we perceive in the organic world—phenomena which differ, whether, on the one hand, the materials are the same, and the forms differ, or, on the other, the materials differ, while the forms are the same.

If, therefore, the vegetable kingdom consisted of one common cellular substance, this being different, however, only as *to the form*, either in various tribes or genera, or species, or parts, or organs of plants; the effects of the same chemical body, of the same cellular substance, must, of necessity, be different for each different form. This has in fact been found to be true. These little individuals, these little cells, become other individuals when different in form, or when connected together in a different manner, though they consist almost of the same substances. The very smallest differences in the

the wood were thickened, what has been separated? Undoubtedly the whole.

To ascertain, however, the composition of this so-called incrusting matter, it will not give correct results to precipitate the dissolved substance, and to analyse it; because, as appeared from the experiments of von Baumhauer (see note, p. 196), and as Fromberg likewise found in all his experiments, the cellulose also is far from being insoluble in alkalies. During the digestion of the substances with soda, the proportion of cellulose is continually diminished; we must not, therefore, call it insoluble in alkali, but only less soluble than the incrusting matter. It is, consequently, impossible that the composition of the so-called incrusting matter—namely, that which together with cellulose exists chiefly in wood,—can be accurately stated by Payen, as represented by $C^{17\frac{1}{2}} H^{12} O^{10}$, if the substance which he analysed was that which is obtained from the alkaline solution by precipitation. The amount of carbon in this incrusting matter must be much greater, as will at once appear if we consider that a large quantity of wood leaves exceedingly little cellulose, and if we compare together the respective compositions of these two substances.

Some points, therefore, remain to be investigated. It is especially of importance to inquire into the nature of the substances, which cold alkalies dissolve from cellulose, and which, according to von Baumhauer's experiments (see the note on Phytelephas), have the same composition as cellulose, and consequently as inuline.

What has, however, been already ascertained as to the cellular matter of plants, is to be regarded as an important contribution to physiological chemistry: the discovery of Payen is, indeed, one of the most valuable which recent times have made to phyto-chemistry.

We have just remarked, that it is exceedingly difficult to separate the incrusting matters. Many chemists have investigated the composition of wood; a few only have determined it with accuracy. The results of Petersen and Schoedler, who analysed a great many kinds of wood,* all gave too

* Annalen der Pharmacie, Bd 17, S. 112.

little carbon. Those of Gay Lussac and Thenard gave too little hydrogen; so that the formula for the composition of wood above mentioned (p. 189), $C^{12} H^{8} O^{8}$, must be rejected as erroneous. According to the experiments of Fromberg, the composition of two kinds of paper, which he analysed, agrees with that of cellulose,* and not with that of wood.

It appeared from a series of experiments, made by von Baumhauer and Fromberg, that for wood we may assume the formula, $C^{64} H^{44} O^{39}$,† which has been deduced chiefly from the hard perisperms of stone fruits.

If from this formula we subtract that of cellulose, then we find for that of the incrusting matter:—

	C	H	O
Wood, ...	64	44	39
Cellulose, ...	24	21	21
Incrusting matter,	40	23	18

It was impossible to obtain this substance directly. By a weak alkali, however diluted, the incrusting or woody matter is changed into ulmic acid, which can be precipitated from the alkaline solution by an acid.

This is the ulmic acid which is mentioned by Peligot;‡ but of which he did not discover the composition. It is the same with that which is produced from sugar by a weak acid—namely, $C^{40} H^{14} O^{12}$,§—it is formed from wood even by a very weak alkali, at the common temperature; and thus the question arises, to which substance is its presence attributable? Not probably to the cellulose, which in this case is so much more difficult to be acted upon; but, no doubt, to the incrusting or woody matter in the first instance. The faci-

* Scheik. Onderz. Deel II.

† Scheik. Onderz. Deel II. As an average result for the composition of wood, we have assumed:

	Found.	Atoms.	Calculated.
C	52.5	64	52.38
H	5.9	44	5.88
O	41.6	39	41.74

‡ Comptes Rendus, 22 Juillet, 1839.

§ Fromberg, in Scheik. Onderz. Deel II. As also, p. 154, *ante*.

lity with which the latter is converted into ulmic acid, is an important fact. The same power, but in a higher degree, is exerted on wood by air and moisture. It is the incrusting matter which putrefies, the cellulose long resisting decay, as is shown in the putrefaction of flax.

We may represent, in the following manner, the transformations which the incrusting matter undergoes during decay—*i. e.* its change, first into ulmic acid, and successively into humic, geïc, apocrenic, and crenic acids (p. 171).

	C	H	O
1 of incrusting matter, ...	40	23	18
And 3 equiv. of oxygen from the air,			3
Are equal to, ...	40	23	21
Or to 9 equiv. of water, ...		9	9
And 1 equiv. of ulmic acid, ...	40	14	12
	40	23	21

If this so-called incrusting matter be produced, either from the cellulose itself, or from dextrin—which is a general principle circulating through the cells, and the common source of cellulose and starch, gums, and sugars,—then, during the formation of wood, hydrogen must be set free, or substances, richer in oxygen than the cellulose, must be produced. If we suppose that, from the cellulose itself, the incrusting matter is directly produced, this may happen in the following manner:—

	C	H	O
2 equiv. of cellulose, ...	48	42	42
1 equiv. of incrusting matter,	40	23	18
Difference, ...	8	19	24

—or along with a small number of equivalents of carbon, a large number of hydrogen and oxygen remain, which may either be given off directly, or may cause the production of other substances.

The formation of wood in plants is a universal process, which takes place even in those which are herbaceous. If,

therefore, this wood is formed only from a general vegetable substance,—that is, a body consisting of carbon and water only —then there is always opportunity for the evolution of oxygen, which is here and there secreted. But if oxygen is set free, and then meets with substances susceptible of oxidation, a new series of oxygenous bodies may be produced during the formation of wood. Hence, perhaps, a source of oxalic acid, which may be produced from sugar, in the different kinds of sorrel, by the influence of the oxygen set free in the production of wood, just as it can be prepared artificially from sugar and nitric acid.* Hence, perhaps, in other plants, there originate other substances rich in oxygen. (See *Evolution of oxygen by plants.*) For it is unquestionable that, by the production of a general substance in plants, containing less oxygen than another, from which it has been produced, different substances, containing much oxygen, must be formed in different parts, according as the substances which exist there, and other circumstances, differ.

Finally, as to the change of wood into dextrin and sugar by sulphuric acid, this change must, of necessity, relate only to the cellulose which the wood contains, in which hydrogen and oxygen are present, in the proportions required to form water. The incrusting matter alone cannot yield this dextrin and sugar. It is not known what changes it undergoes by the action of acids; but certainly the account of the matter given in the present day is wrong.†

* Or from wood by the action of caustic potash.—*J.*

† To the chemical physiologist it will appear not uninteresting, as a further fact concerning this incrusting matter, that the formula by which it is above represented, has so close an analogy with that of the ulmic acid extracted from peat by carbonate of soda, and described by me in page 180, *supra*. These formulæ, calculated to C^{40}, are respectively—

	C	H	O
Incrusting matter, ...	40	23	18
Ulmic acid from Scotch peat,	40	23	15
Difference,			3

The incrusting matter, therefore, which forms so large a proportion of so many plants, can be changed into this variety of ulmic acid by the simple abstraction of 3 equivalents of oxygen.—*J.*

As to the chemical properties of the cellular membranes, which in their natural state consist, not perhaps exclusively, but for the most part, at least, of cellulose, we have to remark, that, in the most recently formed, protein is always present, and though it can be afterwards re-dissolved and removed, it appears to be indispensable to the production of the cells in plants. Payen, at least, always found a substance containing nitrogen in the youngest parts of the roots; and by simply digesting them with a weak alkali, we obtain protein-compounds. Protein appears thus to be just as necessary to the production of cells, as cellulose itself. As, however, the whole or the greater part of the protein afterwards disappears from the cells, it is probably dissolved again by the saps of the plant, and carried to other parts, to be there used for other purposes.

There is another peculiarity still to be remarked, concerning the cellular membrane, namely, that, though it be formed of cellulose, it can yet assume various chemical conditions.

Mohl and Schleiden have demonstrated* that the cellular membrane of many parts of plants is coloured blue by iodine, just as if it contained starch. The embryo of Schotia speciosa, the cells of the cotyledons of Tropæolum majus, hybridum and minus, and those of many other plants, gave a strong blue reaction with iodine.

Though it be true that we ought not to consider the reaction of iodine on the cellular membrane as decisive, it is too important to be passed over, if we consider it in connection with the known reaction of starch. The apparent identity of this reaction would lead us to infer, that cellulose, the composition of which approaches so nearly to that of starch, can really often be modified, as it were, into starch, though it still retains the appearance of cellular membrane. (See *Lichen-starch.*)

As to the composition of the several organs of plants, we are still uncertain. It is true, that Reade has endeavoured to prove,† that the spiral vessels and the cellular tissue are very different in composition, but his analyses are evidently in-

* Flora, 1840, s. 609, cu s. 737.

† London and Edinburgh Phil. Mag., 1837, p. 418.

correct. Mitscherlich, however, has analysed three different organs, and found 45.98 of carbon in flax, 48.88 in the pure spiral vessels of the pisang, and 50.65 of carbon in the cellular tissue of the interior part of the pith of the elder-tree; in all of them hydrogen and oxygen were in the proportions to form water. But these analyses are too few in number to warrant any conclusion. On this point, we are still wholly in the dark. The difficulty of obtaining pure organs ought not, however, to deter us from such an investigation. We are certainly mistaken if we suppose, that the discovery of cellulose has completed the chemical knowledge of the organs of plants; on the contrary, almost all remains to be done for the attainment of a just knowledge of the functions proper to the organs of plants, as far as that can be learned from the chemical nature of the substances composing them. By digesting vegetable substances with an alkali, several products are obtained (the so-called incrusting matters) of which the carbon is almost constant at 46 per cent.—a proportion which it is impossible to reduce to that contained in cellulose. Hence, it would appear that there exists an intimate connection between cellulose and another substance, which is richer in carbon, and which, therefore, deserves to be studied. Finally, for many reasons, I think it wrong to call by the name of incrusting matter every substance, by which the carbon of cellulose is increased.

B. Of the Amylaceous Substances.

There exists a substance very closely related in composition and properties to the cellular tissue of plants, of which three different states are known, though all distinguished by the common name of *starch*. They are, undoubtedly, products either of dextrin or of the cellulose of plants; for which reason they do not belong to the primary, but to the secondary vegetable products. We think, however, they ought to find a place here, because of the great influence they exert on the functions of plants, and because of their frequent occurrence.

These three substances are, common starch, lichen-starch,

and inuline. The first is an intermediate substance between dextrin and cellulose; the second between dextrin and common starch; the third between common starch and sugar. Thus the two latter fill up the interval in the series of the four chief constituents of plants—cellulose, starch, dextrin, and sugar, and their mutual transition is made to appear less abrupt.

Common Starch or Amylum. We have observed in the incrusting matter—by which cellulose is changed into wood—a real juxtaposition; we find this equally in the small granular substances, which appear so frequently in the vegetable kingdom, and which have, in recent times, obtained so much attention from botanists and chemists, and the investigation of which has given rise to so much difference of opinion.

Leeuwenhoek has made an observation as to starch, which has been repeated and extended by many French chemists, and which is denied by some as powerfully as it is defended by others. He found* that the grains of starch, when heated under water, disappeared, and left nothing but membranes. He found the same membranes in the excrements of birds, which feed upon corn, and from these two observations he drew the conclusion, that starch consists of a kernel, which is fit for nourishment, and of an insoluble exterior tegument, destitute of nourishing properties.

This observation was first repeated in 1812 by Villars, and it has, in several respects, been since extended by Raspail. Payen and Persoz, however, have proved,† by a great number of experiments, that starch consists of 0.995 parts of a substance quite insoluble in water. By this discovery they have set aside the observation of others, that starch contains a soluble substance, possessing the properties of gum. They have also ascertained the simple form of the globules of starch, which appear to consist of concentric layers deposited upon each other:—a fact, which

* An elaborate history of starch by Payen is to be found in the Annales des Scien. Natur., Juillet, 1838, p. 8, and Aout, p. 65: as also Cop. Dissertatio Continens quaedam de Amylo. Dordraci, 1841.

† Annal de Chem. et de Physique, 1833, tome 53, p. 73: tome 56, p. 337.

has since been fully ascertained by Fritsche* and others. Payen proved† by several re-agents, that the interior and exterior parts of starch have exactly the same properties, and that they yield the same products with water, iodine, diastase, and acids. He gave figures of the globules of starch, in the state they assumed under pressure, and when acted upon by these re-agents; and no doubt was left as to their uniform composition. It is quite certain, therefore, that the globules of starch consist of a substance, which in all its particles is homogeneous, being composed of concentric laminæ, deposited upon each other, and insoluble in cold water. The form of the globules is either circular or somewhat elliptical in all cases where they are formed, either floating in a liquid, or not entirely filling the cells. If they fill the cells entirely, they become polyedric, assuming various figures, for which reason they have in different plants very different forms, having been influenced by very different circumstances. They exist in the most different parts of plants, and thus conform themselves to the shape of the cells in which they have been deposited.

At the ordinary temperature, starch contains a considerable proportion of water, from which it is separated only by long-continued drying. At 68° Fahr., in the air, it contains 18 per cent. or 4 equivalents;—at 68° Fahr., in the dry vacuum, only 9.92 per cent. or 2 equiv.;—at 212° to 284° Fahr. it consists of $C^{12} H^{10} O^{10}$. Payen thinks,‡ that, in its combinations with bases,—oxide of lead, for instance,—it consists of $C^{12} H^{9} O^{9}$; but this has not been confirmed. In the lead compound also, its constitution is represented by the formula, $C^{12} H^{10} O^{10}$.§

* Poggendorff's Annales, Bd. 32, S. 129.

† Annales des Sc. Nat. 1838, Aout, p. 69.

‡ Annales des Sc. Nat., 1843, Aout.

§ According to Payen, the composition of amylate of lead, dried at 356° Fahr., is as follows (Annal. de Chem. et de Physique, tome 65, p. 253):—

	Found.	Atoms.	Calculated.
C	19.66	12	19.45
H	2.37	9	2.38
O	19.07	9	19.17
Pb O	58.90	2	59.00

If heated to 392° Fahr., it becomes yellow, and a great part of it is then soluble in water. If the same experiment is made with undried starch in a closed tube, it melts entirely

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From potato-starch, dried at 212° and at 293° Fahr., he obtained—

	212°	293°
C	43.81	45.69
H	6.10	6.37
O	50.09	47.94

From this it would appear, that starch cannot be dried at 212° Fahr. Berzelius, however, analysed starch, dried at 212° Fahr., and he obtained—

	Found.	Atoms.	Calculated.
C	44.25	12	44.91
H	6.67	10	6.11
O	49.08	10	48.98

Though it appears from this, when compared with Payen's experiments, that the constitution of starch at 212° Fahr. is really $C^{12} H^{10} O^{10}$, the repetition of the analysis was not superfluous, considering the difference of opinion as to the composition of starch, gum, and sugar, and the positive assertion, that in all these compounds, 2 equiv. of oxide of lead were substituted for 2 equiv. of water. I obtained (Bulletin, 1838, p. 40),—

C	44.47
H	6.28
O	49.25

That is, $C^{12} H^{10} O^{9}$.

2.161 of starch, dried first at 212° Fahr., and then at 356° Fahr., lost no weight. 1.467 starch, dried at 266° Fahr., were converted into boiled starch with hot water, and mixed with 3.114 of oxide of lead, dried at 266° Fahr. The mixture was dried at 284° Fahr., and then in the dry vacuum at 356° Fahr. The quantity was—

	Before the experiment.	After the experiment.
Oxide of lead,	3.114	4.579
Starch,	1.467	
	4.581	

Thus the formula of starch, either dried alone at 212° and 293° Fahr., or in the lead compound, is $C^{12} H^{10} O^{10}$.

When, therefore, cellulose is converted into starch, the separation of ¼ equiv. of water must take place, besides a re-arrangement of the molecules; and, on the other hand, when starch is converted into cellulose, water must be absorbed. The irregularity, that 2 Pb O do not remove 2 H O, may deserve particular attention, but this irregularity does not entitle us to present the facts in another shape than that in which they really exist. Oxide of lead, probably, does not make starch part with the last equiv. of water, except at a temperature at which the starch itself is changed. The analogous fact as to sugar (see the note on sugar) proves, that this last equiv. of water can be retained in the lead compound, even far above 212° Fahr.

at 392° Fahr. through the influence of the aqueous vapour raised to that temperature. When heated with water to 162° Fahr., boiled starch is formed, of which the consistence increases if it be heated to 212° Fahr. The particles of starch are now very much swelled, though they still pass through a filter. The extremities of the fibres of roots, however, cannot take up the globules of starch. If young plants are placed in a solution of starch, they take the water, and precipitate the particles of starch at the surface of the little fibres. This increase in bulk of the starch-globules may be readily effected at ordinary temperatures, by adding a little alkali to the water: diluted sulphuric acid also, though in a less degree, has the same effect.

By diluted acids, at an elevated temperature, starch is converted into humin and humic acid; by fuming nitric acid, into xyloïdine, which, according to Buys-Ballot, consists of $C^{15}\,H^{12}\,N\,O^{16}$, and is formed in this manner:—

$$5\,(C^{12}\,H^{10}\,O^{10}) - 2\,H\,O + 4\,N\,O^{4} = 4\,(C^{15}\,H^{12}\,N\,O^{16})$$

Lassaigne states, that it combines with iodine in an equivalent proportion, the product being the peculiar blue-coloured compound, which enables us to detect the presence of starch. This compound becomes colourless when heated to 151° Fahr.; when cold, it resumes its colour. The globules, though undissolved, are likewise coloured; and thus, in microscopical investigations, iodine is a necessary re-agent for starch, though not, as Payen* asserts, infallible. He states, that 10 equivalents of starch combine with 1 equiv. of iodine as a maximum, and that this is not a chemical combination, but is effected by molecular attraction;—just as, in dyeing cotton, &c., the colouring substances are attracted by the tissues. Payen thinks that a group of starch-molecules unite with a molecule of iodine in virtue of a physical, or so-called capillary action; and hence, it would result that alcohol and other liquids, by which iodine can be dissolved, should continually lessen the proportion of it in the starch compound. This would really be such an approach of physical attraction to chemical affinity, as to deserve particular attention.

* Annal. des Sc. Nat., Aout, 1838, p. 114. See page 207.

It is worthy of remark, that starch in the state of globules may occur in very different parts of a plant, from which it may again disappear under the influence of growth ;—that is, from which it may be dissolved, and carried away to other parts by the sap, to cause there the production of other substances. This peculiarity is the more remarkable, because cellulose—the solid parts first produced in plants, and almost identical in composition with starch,—is also occasionally redissolved under certain circumstances, and, after being first converted into dextrin, is conveyed to other parts of the plant in the form of sap, and is employed in the production of starch ; while this starch, in its turn, may be afterwards changed into other substances.

In young parts of plants, such as the extremities of the radicles, no starch is present, but only cellulose and protein-like substances, as stated by Payen ;* and this is the case also in young shoots, or generally in the young opening parts of a plant. Thus, the starch is not formed before, but after the parts, in which it is deposited, have attained a certain growth, and when the feeding matters taken up are no longer required to form the first necessary parts. Payen could not detect any globules of starch either in the vessels, or in the inter-cellular canals ; if present, therefore, it is in the state either of dissolved starch, or of other substances produced from it. He found it neither in the epidermis, nor in the adjoining cells.

It is further a remarkable fact, that in those bulbs, in the scales of which starch abounds, it disappears in great part, sometimes altogether, when they are exposed to light. Thus the starch becomes annihilated, disappears, under the influence of light ; that is, it is converted into other substances. (See *Chlorophyle*.) Hence the reason, why much less starch is to be found in the parts of a plant which are above the ground, than in those below (roots), and that in plants, whose stalks contain starch, it is found chiefly in the pith. In the several species of cactus, the more distant from the surface the leaves are examined, the larger are the grain of starch. (Payen.)

* Ann des Sc. Nat., Octob. 1838, p. 202, and Memoires sur le Development des Vegetaux.

It is to be inferred from the general origin of solid organic substances, that the globules of starch are formed from the sap, and that their rudiments exist first in a liquid state. Hence, the germ of starch must, in form, be spherical; a small sphere, floating freely in a liquid, from which the dissolved elements of starch are deposited, in the form of laminæ, upon that which is already solidified; thus enclosing by new layers what has already been formed. Each grain or globule, however, is fixed to the walls of the enclosing cell by a hilum, of which small organ the real use is not yet made out. The more freely, therefore, this globule floats in the sap, the more it should be able to increase; and this is really the case, since plants rich in sap contain larger globules than such as are more dry (Payen). Hence, also, the reason why these granules assume various forms, polyedric figures, when many are accumulated in one cell, and so compressed by each other —as, for instance, in maize, where they are covered with a horny integument, or in Cicas circinalis, where about one-half of the globules are round, the other half being polyedric and filling up the spaces left open between the spherical grains. Thus, the latter have been rendered polyedric by mutual pressure. The interposition of little flakes of protein-compounds, or other substances, also makes them assume this polyedric form, as in beans, peas, &c., and generally in the albuminous seeds. As, however, the starch-globules themselves never, in a chemical sense, inclose albumen, but are inclosed by it, we may conclude, that the starchy substance is first deposited in plants, in a solid state, and that then the so-called coagulated albumen is deposited. This is also the case with other substances,—salts of lime, oily matter, &c., —of which occasional traces are to be found on the surface, as well as in the exterior layer of the globules of starch, and by which the solubility of the latter in water is lessened. (Payen.) It has been ascertained, that the starch-globules may be dissolved wholly or in part during the growth of the plant. On this, Payen has made several important observations, from which it would appear, that either their exterior layers are dissolved, or that they wholly disappear. The product of this

dissolution or disappearance, he states to be dextrin and sugar, and the cause of the action, diastase,—a substance, the effect of which upon starch, artificially prepared from plants, is now well known. This is the change which frozen potatoes undergo, where all the starch is converted into sugar. It also takes place in the growth of new potato-plants,—all the starch disappearing from the tuber (the potato), and being replaced by sugar. That diastase is formed in germinating seeds is highly probable, though we do not know a single analysis of it.

According to De Candolle,* the quantity of starch in potatoes increases, as they approach to ripeness, almost in the same degree as it afterwards diminishes. In August, 100 lb. of potatoes, gave 10 lb. of starch; in September, 14.5 lb.: in October, 14.75 lb.; in November, 17 lb. This proportion is constant during January and February, diminishes in March, so as to come down in April to 13.75 lb., and in May to 10 lb.

The same result would be obtained from many seeds and roots, and from amylaceous parts of vegetables in general, if they were analysed with this view. We learn from this, that both the production and the disappearance of starch is a common chemical operation, in which the plant takes no share. It is an action exercised by substances, which are in contact with each other, and may cause this alternate formation and change of starch, through the influence of a rising or falling temperature.

We know better what is produced from starch, than from what starch is produced. As to the former, we learn from experience, that dextrin and sugar are invariably to be found, after starch disappears. It is incontestible, that the same substances may produce starch under circumstances entirely different. Organic nature presents a great many similar phenomena, for instance, the deposition of fat in the animal tissue, and the dissolution of it again at other periods; the deposition of muscular fibres in the muscles, the dissolution of them in sickness, and the re-deposition of them during and after recovery. Such direct and inverse phenomena are

* Phys. Veg., tome i. p. 181.

frequent. In permanent parts of plants starch undergoes the same change. In many plants, it seems to perform a service analogous to that of fat in animals, being deposited as a reserve to be afterwards taken up, and applied to the production of new substances.

There are two other purposes for which starch is known to be employed, besides the formation of dextrin and sugar, namely, the production of fat and of chlorophyle. Both will be treated of hereafter.

Lichen-starch. There are many cellular plants, especially lichens, of which the tissue, when boiled with water, produces a gelatinous substance, having a composition which approaches to that of starch. Its composition, however, is not always the same. In some plants of a similar kind we find a real gum,—in the carigeen moss (Spærococcus crispus) for instance;—for which reason the name of *amylaceous tissue*, which is given to the tissue of these plants, ought to be more limited than it is at present.

Under what form the gelatinous substance, produced by boiling Iceland moss in water, occurs in plants, is not yet known. Though in the fine capillary cells, of which such plants chiefly consist, a great many little globules are found, which are dissolved by boiling in water, their number is insufficient to produce so large a quantity of lichen-starch as can be obtained from these plants. (Meyen, Physiologie.) It is probable that during the boiling this starch is not dissolved, but is produced from some constituent of the plants, which incloses the cellular substance. We see the cellular membranes gradually dissolving, so as to become thin and loose, instead of thick and solid, as they were before. When boiled sufficiently, and further extracted by the solvents, which we mentioned in speaking of cellulose, the final residue of these plants is nothing but cellulose (see p. 189). It is improper, therefore, to call the whole tissue of the plant, *amylaceous tissue*. It consists of real cellulose, $C^{24} H^{21} O^{21}$; and of a certain substance besides, which, by boiling, is changed into the well-known lichen-starch.

It had been stated before by Payen, that the starch of the

Lichen islandicus (Iceland moss), contains also inuline.* He afterwards found this observation confirmed;† but the proportion of inuline is exceedingly small. If a decoction of the lichen be thrown down by sub-acetate of lead, the precipitate consists wholly of amylate of lead, the inuline being retained in solution. If sulphuretted hydrogen be passed through the filtered liquid, only a little un-crystallisable sugar, produced from the inuline, is obtained after filtering and evaporation. The composition of the organic part of amylate of lead is the same as that of common starch,—$C^{12}\,H^{10}\,O^{10}$, and not $C^{12}\,H^{9}\,O^{9}$, as stated by Payen.‡

Now, as the formula of the cellulose from all kinds of plants, and therefore also from the lichens, is $C^{12}\,H^{10}\,O^{10} + \frac{1}{2}$ aq.,

* Berzelius, Lehrbuch, Bd. VIII., S. 452.

† Annal. des Sc. Nat. Août, 1840, p. 85, Bot.

‡ It appeared from analyses of lichen-starch, which I made in 1838, that it has this composition. (Bulletin, 1838, p. 41.)

	Found.		Atoms.	Calculated.
	I.	II.		
C	44.71	45.13	12	44.92
H	6.26	6.30	10	6.11
O	49.03	48.53	10	48.97

I found that the equivalent weight of this starch is 1021, or the half of $C^{24}\,H^{20}\,O^{20} = 2042.04$. In these experiments, I also observed that the decoction, after subsidence, was turned somewhat blue by iodine, the remainder becoming yellow. These two separate colours produce green when the substances are mixed together. I observed then, that the colour was the same, as if common starch and inuline had been dissolved in water, and iodine added; the colour being then also green.

Payen has since demonstrated the presence of inuline, and this has been completely ascertained in the manner mentioned above.

Thus, if we precipitate a decoction of the lichen with alcohol, we obtain a mixture of starch and inuline; and though the sole difference in their composition is $\frac{1}{2}$ equivalent of water (HO), yet it was still desirable to analyse pure lichen starch, wholly free from inuline.

For this purpose, Beckers precipitated a solution of lichen-starch in water, by basic acetate of lead; the inuline then remained in solution. After the precipitate was properly washed, and dried at 248° Fahr., the composition was —

C 44.48
H 6.00
O 49.52

The composition of starch—namely, $C^{12}\,H^{10}\,O^{10}$—being thus the result, again.

the formation of lichen-starch is not difficult to explain. For cellulose and dextrin are in general to be considered as the sources of starch and sugar in plants; the cellulose, in its turn, being produced from dextrin. We find, however, that cellulose contains ½ equivalent of water more than common starch; so that there is not only a physical, but also a chemical difference between these two substances. For the same reason, Lichen-starch, free from inuline, is not cellulose, being chemically different from it.

But lichen-starch, free from inuline, is also different from common starch. We have learned this already, from the peculiar change of colour caused by iodine in a decoction of lichen-starch. This decoction contains only a very small proportion of inuline; nevertheless, its colour, when mixed with iodine, is green. In a solution containing common starch, this green colour could appear only where little starch and much inuline were present. If a diluted decoction of Iceland moss, after being coloured with iodine, is allowed to settle for a while, the layer at the bottom is yellow, and that immediately above is blue. Thus the decoction contains *both* common starch and inuline. But as the proportions of the substances, coloured respectively yellow and blue by iodine, are not the same as those of the starch and sugar (the latter produced from inuline), which are separated from the decoction by basic acetate of lead, there must exist in the Iceland moss a third kind of starch; one, namely, which, like inuline, is turned yellow by iodine, and, like common starch, can be precipitated by basic acetate of lead. It must even constitute the chief part of the lichen-starch.

Nothing, however, is more in accordance with the character of natural products, than the existence of transition-forms between cellulose and other substances, nearly approaching either to starch and dextrin, or to starch and sugar;—as these three substances are undoubtedly produced from the cellular tissue itself, or at least from such molecules, as, being predisposed to produce cellular substances, have only to assume another arrangement, under a slight difference of circumstances.

In other species of moss, other kinds of starch also are

found. If we boil the Lichen fastigiatus, we obtain a sort of starch, which, like that from the Lichen islandicus, becomes covered with a pellicle when evaporating, but does not gelatinise when cooled. Though insoluble in cold water, it swells in it to a jelly. The Lichen fraxineus, when boiled, produces a similar kind of starch, which does not become a jelly on cooling. The Lichen fastigiatus gives a transparent, gelatinous precipitate with basic acetate of lead, with which also common starch, and that from Iceland moss, give an abundant precipitate; while the decoction of Lichen fraxineus gives no precipitate. An infusion of gall-nuts, which precipitates common starch, and that from Iceland moss, does not act upon those from Lichen fastigiatus and Lichen fraxineus.

Thus, there are several varieties of starch, which are probably combinations of common starch, either with dextrin or with sugar; of the latter we have an instance in *inuline*.

The starch of the cryptogamic plants has often been investigated. Its reaction with iodine, for instance, has been examined by Vogel,* and after him by Dietrich.† Vogel found that the starch from the Lichens was coloured green by iodine, instead of blue. Meyen, however, asserts that the whole tissue of plants gives a blue with iodine; but as this substance is not converted into a jelly by boiling, as common starch is, it has been called by Schleiden, *Amyloïde*. Common starch has been found, by Vogel, in the stalks of the Lycopodiaceæ, in the cellular tissue of Rhizocarpeæ, in the so-called anthers of Chara; by Dietrich in the Parmelias, in Sticta pulmonacea, Sphaerococcus crispus, Sphaerococcus helmintochorton, &c. We have, however, already seen (p. 205) that the reaction with iodine is not sufficient to prove the existence of starch, as Mohl and Schleiden have observed the cellular membrane in many plants turned blue by iodine. A great many transition forms intervene between cellulose and inuline, common starch being only one of them.

Inuline. In many plants, but especially in Dahlia, Helenium, and Taraxacum, there is found, even much more generally than

* Linnæa, Bd. 13, S. 39.

† Erdmann and Marchand's Journal, 1842, Bd. 25, Heft 6, S. 377.

common starch, a substance which, though hitherto almost always overlooked, can be extracted by boiling water, and is precipitated by cooling; which, after repeated boiling and cooling, remains finally soluble; which, being boiled a long time in water, is changed into un-crystallisable sugar,* and which, as Payen states, undergoes a similar change by the action of acetic acid.† The proportion of carbon it contains is slightly different, according as it is in the state in which it readily precipitates from a cooling solution—its carbon being then at the highest point; or in the state in which it is soluble in cold water—its carbon being then at the lowest.

This substance was subjected to a great many analyses before its real composition was ascertained.‡ It is surprising

* Bulletin, 1838. Onderzoek. Deel I.

† Ann. des Sc. Nat. Août, 1840, Botan., p. 86.

‡ By analysing inuline from Taraxacum and Helenium, I found its composition to be as follows (Bulletin, 1838, p. 41):—

	Taraxacum.	Helenium.	Atoms.	Calculated.
C	44.75	45.04	12	44.91
H	6.20	6.28	10	6.11
O	49.05	48.68	10	48.98

Parnell found afterwards (Annal. der Pharmacie und Chemie, Bd. 39, S. 213) the composition of inuline from the Dahlia to be as follows:—

	I.	II.	III.	Atoms.	Calculated.
C	43.95	44.07	43.90	24	43.71
H	6.34	6.45	6.41	21	6.25
O	49.71	49.48	49.69	21	50.04

By adding to a solution of inuline, acetate of lead, and afterwards ammonia, he, in two preparations, obtained two different precipitates:—

	Found.	Atoms.	Calculated.
C	16.65	24	16.42
H	2.44	21	2.35
O	18.48	21	18.81
PbO	62.43	5	62.42
	Found.	Atoms.	Calculated.
C	22.46	24	22.81
H	2.94	18	2.79
O	23.37	18	22.38
PbO	51.23	3	52.02

From analyses by Croockewit (Scheik. Onderz. D. I.) it appeared, that those of Parnell are accurate. He found—

		For Inuline from Dahlia.	
C	43.95	43.94	44.01
H	6.30	6.28	6.21
O	49.75	49.78	49.78

to see how readily it is changed into sugar; and as it can combine with the sugar, and carries this sugar with it, especially in its combinations with bases, it necessarily follows, that the elementary analyses of inuline from different plants and different preparations, as well as of its combinations with other substances, must give different results. The composition of inuline, when insoluble in cold water, is $C^{12} H^{10} O^{10}$. It has, therefore, the composition of starch, with which it possesses also some properties in common; however, it is neither changed into a jelly by warm water, nor does it turn blue with

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That is = 2 ($C^{12} H^{10} O^{10}$) + HO.

	For Inuline from Helenium.	
C	44.30	44.41
H	6.23	6.26
O	49.47	49.33

That is = 2 ($C^{12} H^{10} O^{10}$) + ½ HO, or ½ Aq. more than I found.

He analysed lead salts of inuline from Dahlia and Helenium; these salts being prepared from the same quantities of inuline, dissolved in the same quantity of water, and precipitated by the same mixture of acetate of lead and ammonia. These lead salts mutually differed, but still more so, when, with the same manner of preparation, other quantities were taken.

I. Helenium.

	Found.	Atoms.	Calculated.
C	21.52	24	22.81
H	2.65	18	2.79
O	22.56	18	22.38
Pb O	53.07	3	52.02

I. Dahlia.

	Found.	Atoms.	Calculated.
C	25.20	32	26.22
H	3.32	24	3.21
O	27.56	24	25.72
Pb O	43.92	3	44.85

II. Helenium.

	Found.	Atoms.	Calculated.
C	19.13	24	19.22
H	2.39	19	2.48
O	20.61	19	19.89
Pb O	57.87	4	58.41

II. Dahlia.

	Found.	Atoms.	Calculated.
C	17.38	16	18.10
H	2.16	12	2.22
O	18.32	12	17.76
Pb O	62.14	3	61.92

iodine, but yellow. It may just as well be called a variety of sugar, insoluble in cold water, and destitute of taste, as a variety of common starch. The above mentioned composition was that given by inuline from Taraxacum and Helenium. By another method of preparation, in which the inuline was made more easily soluble after the warm solution was cooled, it had this composition :—

$$2\,(C^{12}\,H^{10}\,O^{10}) + \tfrac{1}{2}\,Aq.$$

The inuline from Dahlia-roots—that which is more, as well as that which is less soluble in the cooled solution, had this composition :—

$$2\,(C^{12}\,H^{10}\,O^{10}) + HO.$$

This increasing proportion of water is owing to an admixture of un-crystallisable sugar, with which inuline combines intimately.

We see no simple relation among these four lead salts, prepared two by two in the same manner. Putting Aqua for Pb O, we have—

For Helenium, I. ... ... $C^{24}\,H^{18}\,O^{18} + 3\,Aq$
... II. ... ... $C^{24}\,H^{18}\,O^{18} + 5\,Aq$
And for Dahlia, I. ... ... $C^{36}\,H^{24}\,O^{24} + 3\,Aq$
... II. ... ... $C^{36}\,H^{24}\,O^{24} + 6\,Aq$

Thus they appear to contain a different substance. It has been ascertained that these inulates of lead contained glucates, pure inulates perhaps not existing.

From this, it is inferred that inuline, where it becomes soluble in cold water, is no longer a pure chemical compound, but a combination of un-crystallisable sugar (glucose), with precipitable inuline.

This has been completely confirmed by Payen's analyses (Ann. des Sciences Natur., Août, 1840, p. 91), who found in the two varieties,—

1° Common Inuline.

	At 302° Fahr.	Atoms.	Calculated.
C	44.55	24	44.91
H	6.12	20	6.11
O	49.33	20	48.98

2° Soluble Inuline.

	At 338° Fahr.	Atoms.	Calculated.
C	44.19	24	43.71
H	6.17	21	6.25
O	49.64	21	50.04

Payen does not admit this distinction, but calls them isomeric. From the above experiments, however, and from the fact, that a greater proportion of carbon was obtained in his first analysis, the conclusion is incontestible, that precipitable inuline contains less water than the soluble modification.

If we try to produce combinations of inuline with bases, the product is always a mixture of an inulate with a glucate. The uncrystallisable sugar, existing already in inuline, is changed into glucic acid by a base. It is highly probable, that pure inulates do not exist at all.

Does pure inuline exist? As far as experiment entitles us to say, this is doubtful. It is a necessary consequence of the only method of separating it from plants, that a little sugar must immediately be formed, which combines with the unchanged inuline. But, on the other hand, it appears that the change of inuline into sugar takes place in the plant, for which reason a difference of one-half, and even of one equivalent of water, may really exist between the inuline from Helenium and that from the Dahlia.

From the great facility with which inuline is convertible into sugar, it must, like dextrin, be placed between sugar and common starch. In many plants, dextrin is a transition substance from common starch to sugar, as is the case when either sulphuric acid or diastase acts on common starch. In other plants, inuline is such a transition substance between common starch and sugar, without the formation of dextrin; perhaps, likewise, between cellulose and sugar. This is the reason why inuline exists in many plants; and why on suddenly disappearing at certain periods, it causes the parts of plants to become sweet.

As the composition of unchanged inuline is exactly the same as that of cellulose, it is probably produced from the latter, and not from common starch.

Raspail thought he observed an intimate connection between common starch and inuline, because the tubers of Helianthus tuberosus contain occasionally common starch, instead of inuline. This fact, however, in my opinion, proves nothing; for the roots of the carrot, in its wild state, contain almost no sugar, and are inedible: the cellulose being converted into wood. This is also the case with many other cultivated plants.

Meyen has made the observation, that in fresh Dahlia-roots, inuline exists in a state of solution, and can be deposited in the shape of globules, by freezing. He states that these globules resemble those of common starch in that two, three,

or more adhere together, but that they are different, in so far as they are not formed of concentric layers. In the fresh and growing tubers, before freezing, not a trace of these globules is to be perceived. The sap from Dahlia-roots may be filtered through paper and clarified by albumen, and yet, when evaporated and cooled, inuline is deposited as a precipitate.*

C. Dextrin and Gum.

By roasting common starch, or by treating it with a certain substance, existing in malted barley, and called *diastase*, or with diluted sulphuric acid, it is changed into a substance, which is soluble in water, and which exists in almost every part of plants. This substance is called *dextrin*, and, in a physiological point of view, ought not to be confounded with what we usually call *gum*. The latter exudes from the bark of many kinds of acacia. After being exposed to the air and separated from the water by drying, it appears as an almost chemically pure substance, similar to dextrin in most of its properties, and in composition. The formula for both is the same as that for starch, namely, $C^{12} H^{10} O^{10}$.† When starch is boiled in water for some time, an abundance of dextrin is produced.

Dextrin may also be produced from cellulose, both by diastase and by sulphuric acid: by the latter dextrin may be produced also from incrusted cellulose (wood). As, however, the composition of the incrusting matter of wood is different from that of cellulose, not containing hydrogen and oxygen in the proportions which form water, other compounds must necessarily be produced, which, however, are not yet ascertained (p. 202). An exceedingly small quantity of diastase is required to convert starch into dextrin. If the action of diastase or of

* Pflanzen Physiologie, Bd. 2, S. 284.

† According to an analysis of Berzelius, gum arabic consists of

	Found.	Atoms.	Calculated.
C	42.68	12	42.58
H	6.37	11	6.37
O	50.95	11	51.05

and it is bi-basic, that is, combines with two equivalents of oxide.

Payen states the composition of dextrin to be $C^{12} H^9 O^9 + 2\,RO$, so that 2 of oxide of lead are substituted for two of water. He has been led to this conclu-

diluted sulphuric acid be continued too long, or if the quantity of either be too large, grape-sugar is produced.

It is, no doubt, by similar means, that Nature converts cellulose into dextrin, and dextrin or starch into sugar. She may not, however, employ diastase. It is possible that plants contain some other substance, by which cellulose is changed into dextrin. But as, in malting barley, diastase is produced from starch, without the aid of art, it may also be produced in the growing plant, and convert cellulose into

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sion by Dumas, who thought that dextrin, dried at 356° F. must lose all its water, through the influence of a metallic base. Though the results of Payen's analysis, made with dextrinate of lead, confirm this view (Ann. de Chem. et de Physique, tome 65, p. 249).

	Found.	Atoms.	Calculated.
C	19.2	12	19.45
H	2.4	9	2.38
O	19.3	9	19.17
Pb O	59.1	2	59.00

yet at a much lower temperature than 356°, namely, at 275° Fahr., gum turns yellow, and at 356° dextrin ceases to be dextrin (Bulletin, 1838, p. 132). At 320° Fahr., gum gives off an empyreumatic smell, and the analysis of it then gave

C	46.11
H	6.06
O	47.83

This substance, therefore, is no longer gum, but a mixture of pyrogenous matters. I got the following results from the under-mentioned sorts of gum, dried at 266° Fahr.

	Gum Arabic.	Gum Senegal.	Gum Java.
C	45.10	44.92	45.22
H	6.10	6.09	6.09
O	48.80	48.99	48.69

	Atoms.	Calculated.
C	12	44.92
H	10	6.11
O	10	48.97

I obtained from gummate of lead, prepared from gum arabic, dried at 266° Fahr

C	45.29	45.23	44.98
H	6.10	6.01	6.00
O	48.61	48.76	49.02

These the composition of gum is identical with that of common starch, and not $C^{12} H^{9} O^{9}$, as asserted by Dumas and Payen. We have no reason to suppose that of dextrin to be different.

dextrin. Every formation of dextrin, which takes place in the plant itself, is probably preceded by that of a substance similar to diastase; the production of dextrin either from cellulose or from starch being merely a chemical process, in which the plant does not take the least part.

The sap of almost all plants contains a certain amount of dextrin. In the published analyses of the greater part of plants, it is called gum. If one equivalent of water be taken from one equivalent of cellulose, two equivalents either of gum or of dextrin are formed. Thus a part of the cellular membranes may be converted into dextrin by catalytic action, without destroying the cell, if the vegetable sap, while passing through the cells, only contain a very minute quantity of a substance, possessing the properties of diastase. Though this substance has not yet been detected in plants, we are sufficiently entitled to hold its existence as probable, and to compare the production of dextrin in plants with its production by artificial means.

What we usually call gum, ought not to be confounded with dextrin. There is a real difference between them. The latter may be changed into grape-sugar by sulphuric acid and by diastase; a property which the former does not possess. The difference is an important one, as regards both their origin and their products.

Dextrin belongs to the nourishing substances. All the starch taken as food, is converted into dextrin. The gastric juice possesses the power of changing starch and cellulose into dextrin.

The various sorts of gum prepared by nature, differ but slightly in their properties. They all contain a certain proportion of bases, and are to be considered as gummates of potash, lime, &c., mixed with pure gum. They all leave an ash when burned. Since they originate from vegetable substances, which are all, more or less, mixed or combined with bases, gum cannot appear as a chemically pure substance. In the gum of the plum and cherry trees, &c., we find resinous colouring matters, a little bassorine, &c.; for this reason, it must be called a less pure kind of gum. The gum from the acacias

is by far the purest of all, though, from the mode of production, it can never be chemically pure. Hence it appears, why different kinds of gum exhibit different reactions with different chemical substances. All these sorts of gum are excretions of the plant; being probably produced from dextrin, without, however, being, like it, convertible into sugar. Dextrin is an important constituent of the sap of plants. Gum is a product of comparatively little moment to the plant itself, and is found in some plants only. Dextrin, on the contrary, is a universal constituent of plants, and must be present during their growth; so great is its importance in the sap of plants.

If we consider the formation of cellular substance (which is insoluble in water), in such different parts of the plant—a process that can only originate from substances, supplied by a liquid, and penetrating through the pores of the cells, *i. e.*, from a dissolved substance,—we are led irresistibly, as it were, to suppose that dextrin is employed for that purpose. For it is a universal constituent of plants;—is almost never absent, whatever may be the part or sap of plants that is analysed. We do not know any other substance the properties of which fit it so well for this purpose. We may assume as a fact, that the sap of plants must contain the elementary matter of cellulose, and that in a state of solution, so as to be able to penetrate through the cell walls, and to supply new cellular substance to increase the number of cells. No other material but dextrin itself is fitted for this office, though, in young plants, sugar contributes to it also. By the production, during germination, of dextrin and sugar, which are formed from the starch of the seeds through the agency of albumen, (see *Sugar*), we are led to suppose, that the cellulose of the young plant is really formed from this dextrin, and from the grape-sugar in the germinating cotyledons. We intend to explain this farther, when treating of the nourishment of plants. It may be sufficient for the present to observe, that many full-grown plants do not contain any sugar; whilst, on the contrary, they all contain dextrin, so that no room is left to doubt that the use of the latter is to form cells.

Neither is there any doubt, as to the part of the plant in which dextrin is produced. The extremities of the rootlets deserve especial notice in this respect. The series of cells, which there spread themselves out, are certainly formed from dextrin. Thus their first origin is visible in that part of the plant. A solution of dextrin, becoming organized, is the source of cellulose; at all events, it is the solution of a substance, consisting of carbon and water, whose composition must be the same as that of dextrin, up to the very point at which cells are produced. From these rootlets it may pass throughout the whole plant; but in other places also, dextrin must be produced, as, for example, wherever the cell walls are dissolved. (See *The Formation of Cells.*)*

As, therefore, dextrin is a source of cellulose, so is it of starch and sugar, and perhaps of other vegetable products besides. It is also a source of the gum in plants;—this substance accumulating in the intercellular canals, sometimes to a considerable extent, or collecting in great quantities beneath the inside of the bark, whence it oozes out through small openings, and thus constitutes the gum arabic, the cherry tree gum, &c. De Candolle mentions that a mass of about 40 pounds weight had exuded through one single opening, in the bark of the Unacardium orientale.

We can scarcely mention any substance in the vegetable kingdom which is of greater importance than dextrin. It is almost as valuable to plants, as protein is to animals—for it is a constituent, from which their organism derives its most important products.

Taking the composition of dextrin to be the same as we found that of gum, the formation of cellulose from it consists in its taking up ½ equiv. of water. Thus—

$$2\,(C^{12}H^{10}O^{10}) + HO = \text{Cellulose.}$$

The production of starch from dextrin is effected simply by an isomeric re-arrangement of dextrin; both having the same composition. This is also the case in the formation from

* In the species of Cactus, we find, throughout the whole plant, an abundance of dextrin in the sap of the plant.

dextrin, of gum arabic, gum senegal, and of plum and cherry tree gums, these being also mutually isomeric. Finally, the production from dextrin of sugar—which is different in kind, according as it is extracted from the cane, from the grape, or from fruits—consists in the mere separation of a portion of water, or in its combination with an additional quantity.

D. Sugar.

The elementary formula of the sugar prepared by plants, is $C^{12} H^9 O^9$; thus the only difference between sugar, and the various modifications of cellulose and starch, on the one hand, and dextrin and gum, on the other, is in the proportion of water they severally contain. Sugar exists in many plants ready formed. In the animal kingdom it also occurs occasionally, as a product of disease in diabetes mellitis. One of the products of the decomposition of gelatine by alkalies, is a kind of sugar, which, although containing nitrogen, yet manifests an intimate connection with common sugar. The different species of sugar, whether of animal or of vegetable origin, as far as they are known, are—

1° Milk-sugar:—

$$C^{24} H^{19} O^{19} + 5\,HO.*$$

2° Cane sugar:—

$$C^{12} H^9 O^9 + 2\,HO.†$$

* *Milk-sugar*, according to Berzelius, consists of

	Found.	Atoms.	Calculated.
C	40.13	24	40.46
H	6.76	24	6.61
O	53.11	24	52.93

At 248° Fahr. the formula is $C^{24} H^{21} O^{21}$, at 302° Fahr. $C^{24} H^{19} O^{19}$, and in its combination with lead, $C^{24} H^{19} O^{19} + 5\,PbO$, or $10\,PbO$.

† *Cane-sugar* has also been analysed by Berzelius, by Gay Lussac and Thenard, and others; and finally by Peligot and myself (Ann. de Chem. et de Phys. T. 67, p. 120).

	Berzelius.	Gay L. and Th.	Peligot.
C	42.22	42.47	42.26
H	6.60	6.40	6.60
O	51.18	51.13	51.14

3° Grape sugar, diabetes sugar, honey and starch sugars, and fruit sugar :—

$$C^{12} H^{12} O^{12} + 2\,HO.^*$$

To this class belongs also the un-crystallisable sugar (syrup of potatoes), called *glucose* by Dumas, and by others fruit-sugar.

	Atoms.	Calculated.
C	12	42.11
H	11	6.37
O	11	51.52

When combined with oxide of lead, one equivalent of water is expelled at 212° Fahr. (Bulletin, 1839, p. 300); the composition is then :—

	Found.	Atoms.	Calculated.
C	18.76	12	18.99
H	2.69	10	2.58
O	21.40	10	20.70
Pb O	57.15	2	57.73

This being the result which had previously been obtained by Berzelius. Precisely at 285.8° Fahr. (141° C.) saccharate of lead begins to lose the second equivalent of water; and if dried at 302° Fahr. the salt that remains has the composition :—

	Found.	Atoms.	Calculated.
C	19.40	12	19.44
H	2.50	9	2.38
O	18.91	9	19.07
Pb O	59.19	2	59.11

It is very remarkable that the sugar, after having taken 2 equivalents of oxide of lead, retains this last equivalent of water so powerfully, till a temperature of 285.8° Fahr. is attained.

* *The sugar of grapes, honey, starch, fruits, and that produced in diabetes,* have all the composition represented by $C^{12} H^{14} O^{14}$. They have been examined by De Saussure, Prout, and Peligot (Ann. de Chem. et de Physique, T. 67, p. 142).

	Grape-sugar.	Starch-sugar.	Honey-sugar.
C	36.71	37.29	36.36
H	6.78	6.84	} 63.64
O	56.51	55.87	

	Diabetes-sugar.	Atoms.	Calculated.
C	36.7	12	36.8
H	7.3	14	7.0
O	56.0	14	56.2

If heated to 284° Fahr., this sugar loses 2 equivalents, or 9 per cent. of water; the formula being then $C^{12} H^{12} O^{12}$. Peligot states, that the lead-salt, if dried at 302° Fahr., is represented by $C^{24} H^{21} O^{21} + 6\,PbO$.

The un-crystallisable sugar, which is obtained during the decomposition of many plants, has the same composition as crystallisable grape-sugar.

From starch, when acted upon by diastase and sulphuric acid, the same un-crystallisable sugar is produced. There is no doubt that dextrin, the primary material of a great number of substances in plants, produces sugar by the action of some substances existing in such plants. We know that by diastase cellulose is changed into dextrin and sugar.

4. Eucalyptus sugar:—

$$C^{24} H^{19} O^{19} + 9 H O *$$

* *Eucalyptus sugar.*—This is a species of manna produced in Van Dieman's Land by various species of Eucalyptus. It is either the natural sap of the tree which flows out spontaneously—or is made to exude in consequence of the punctures of an insect there called the locust,—and which, after being concreted by the sun, is shaken off by the wind; or, as some think, it is the sap extracted by the locust, and afterwards excreted in the same way as the honey-dew, found on the leaves of many trees in this country, is supposed to be excreted by Aphides.

For the discovery of the peculiar nature, and for the analysis of this sugar, we are indebted to Johnston. I insert the following particulars regarding it, with which he has furnished me.

"This sugar occurs in light, yellowish white, rounded concretions, composed of confused tufts of minute crystals, and it often falls in sufficient abundance to whiten the ground beneath the trees on which it is produced. It is less sweet than cane-sugar, and in its natural state, has the smell of honey. Hot alcohol dissolves it, and on cooling deposits the pure sugar in long slender-prismatic crystals, colourless, and without smell, and having a great resemblance to mannite, but differing much from it in composition.

The relations of this sugar to water are very interesting.

"In the state of crystals it is represented by—

$$C^{24} H^{19} O^{19} + 9 H O$$

"If these crystals are heated rapidly at 200 or 212°, they melt and lose 11.35 per cent. of water. In the glassy state it assumes when thus fused, it may be kept for a length of time at 212° without suffering much further loss. It is now represented by—

$$C^{24} H^{19} O^{19} + 4 H O$$

The mean of five determinations of the loss at this temperature was 11.20 per cent., and when analysed in this state, it gave—

	Experiment.	Equivalents.	Calculated.
C	40.43	24	41.03
H	59.57	23	58.97
	100		100

approaching in its formula to milk-sugar, but differing from it very much in its origin and properties. (Johnston.)

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c. But if the crystals be slowly heated, and kept for several hours at 150 to 100° *without fusion*, they will lose nearly 16 per cent. of water, and may then be heated to 280°, at which they begin to melt, and may even be kept for hours at 300°, without undergoing further loss. The sugar is now—

$$C^{24} H^{19} O^{19} + 2\,H\,O$$

Four several portions so heated, lost respectively, 15.23, 15.14, 15.38, and, 16.09 per cent.—three equivalents being, by calculation, 15.89 per cent. Two of these portions gave on analysis:—

	I.	II.	Equivalents.	Calculated.
C	42.57	42.42	24	43.24
H	6.44	6.59	21	6.30
O	50.99	50.99	21	50.46
	100	100		100

If the sugar be melted before the water is driven off, the two latter equivalents leave it very slowly, and it becomes brown, and suffers partial decomposition before it is all separated.

d. If the dried or crystallised sugar be intimately mixed with an excess of oxide of lead, and then gradually heated to near 300° Fahr., it loses two more equivalents of water, and becomes—

$$C^{13} H^{19} O^{19} + 2\,Pb\,O$$

Two portions heated, first alone to 200° without fusion, and then to a higher temperature after admixture with oxide of lead, lost respectively—

	I.	II.	Calculated.
Alone,	15.76	16.00	15.89
Mixed with Pb O,	21.34	20.33	20.82

The sugar, therefore, retains 2 equivalents of the water, which appear to leave it only when replaced by two of a base. Hence the crystallised sugar must be represented by

$$C^{24} H^{19} O^{19} + 2\,H\,O + 7\,Aq.$$

e. The sugar has a strong affinity for the whole of this water, for if, after being dried, it is exposed to the air, it gradually absorbs as much as makes up the nine atoms, and shoots again into crystals. After being heated with oxide of lead, it had, by two days' exposure to the air, taken up 7 of the 9 atoms it had previously lost.

f. A solution of the sugar in water gives, with a solution of acetate of lead on the addition of a little ammonia, a lead-salt containing 7 equivalents of oxide (7 Pb O), and which, when dried at 250° with care, contains 71 per cent. of oxide of lead, and is represented by

$$C^{24} H^{19} O^{19} + 7\,Pb\,O$$

The presence of this large proportion of oxide of lead, however, appears to render the sugar more readily decomposable, when kept long at a temperature approaching 300° Fahr. For while the analysis of one portion of the lead-salt, after being heated, gave the carbon and hydrogen in the proportion of C^{24} to H^{19},

5° *Gelatine Sugar.** Sulphuric acid, when acting upon gelatine, forms a kind of sugar, containing nitrogen, represented by—

$$C^8\ H^9\ N^2\ O^7$$

If from this we subtract, $C^6\ H^5\ \ O^5 = \frac{1}{2}$ equiv. of cane-sugar

There remains, ... $C^2\ H^4\ N^2\ O^2$ = urea.

It thus appears that an intimate connection exists among

another portion, prepared separately, gave me C^{24} to H^{17}. But on diffusing this salt through water, and decomposing it by sulphuretted hydrogen, the watery solution, when evaporated to a small bulk, and mixed with alcohol, gave a precipitate of gum (dextrin?). A portion of the sugar, therefore, had been decomposed, and converted into gum. It would have been very interesting had my stock of material—for which I have to express my obligations to Sir William Hooker—enabled me to investigate more fully, and to establish the reality of this change, which, though it no doubt often takes place in the plant, is the reverse of that which we have hitherto been able to effect by art. It would have been more interesting also from the fact that dry mucilage or bassorine is represented by the same formula as dry Eucalyptus sugar. (See p. 240.)

g. This sugar has very interesting relations to the other known varieties of sugar.

To *cane-sugar* it has little resemblance. It agrees with it in being readily blackened by sulphuric acid, but it differs from it in being blackened also by caustic alkalies.

Like *grape-sugar*, it may be represented in the crystallized state by $C^{12}\ H^{14}\ O^{14}$, but it differs from it altogether in the quantity of water it loses at 250°, and in being blackened, and decomposed by caustic alkalies.

Mannite is very much like it in its solubility in boiling alcohol, and in the priamatic crystals in which it separates as the alcoholic solution cools. But mannite differs from Eucalyptus sugar in losing no water when heated, and in dissolving in concentrated sulphuric acid without decomposition; while the Eucalyptus sugar forms a dark reddish brown solution, without the aid of heat, from which a black acid is gradually deposited.

To *milk-sugar* it bears the closest analogy. Both, when in combination with oxide of lead, are represented by $C^{24}\ H^{19}\ O^{19}$, but milk-sugar loses all its water when heated alone to 300°, while in the same circumstances, Eucalyptus sugar is still $C^{24}\ H^{21}\ O^{21}$. Milk-sugar is also *very* much less soluble, both in water and in alcohol."

I may farther remark that both of these sugars are distinguished by the large quantity of water they contain.

Were we certain that the Eucalyptus sugar is derived directly from the sap of the tree, this circumstance would do away with the supposed character of animal sugars, that they contain a larger quantity of water than vegetable sugar; on the other hand, if it be really excreted by insects, this alleged characteristic property will become more probable.—*J.*

* The composition of *gelatine sugar* is as follows (Bulletin, 1838, p. 146, and Scheik. Onderz. Deel I.):—

the different kinds of sugar—a connection including even cellulose, common starch, lichen-starch, inuline, dextrin, and all kinds of gum. All these substances contain carbon, in combination with hydrogen and oxygen in the proportions requisite to form water. As they all contain C^{12}, or a multiple of it, they are produced from each other by a very simple change—by a mere catalytic action; and thus the process by which they are formed in plants and animals, is a purely chemical one.

Cane-sugar is the most closely related to starch and dextrin, though it differs from them in containing one equivalent less of water. It is probable that in fruits, this kind of sugar is first produced, and that it is afterwards converted into grape-sugar, by taking up three equivalents of water. The facility with which grape-sugar is produced from cane-sugar, either by fermentation, by diastase, or by weak acids, is well known. It is remarkable that,—the sugar-cane, the beet, the maple-tree, and a few other plants excepted,—we uniformly find in all others, grape-sugar $C^{12} H^{14} O^{14}$, and not cane-sugar $C^{12} H^{11} O^{11}$. Thus, it would appear, that in plants containing the latter, certain substances (acids?) are wanting, which induce the primary substance, $C^{12} H^9 O^9$—which we may suppose to be present in cellulose, starch, dextrin, and gum, and also in cane-sugar—to take up more water. Glucose, already mentioned among the analyses, seems to be produced either from inuline or from crystallisable sugar, during the decomposition of some parts of plants (see page 223). This is also true of the syrup produced in preparing cane-sugar. Under the present improved process, much more crystallisable sugar is obtained than formerly, in treating the sap from sugar-cane, and in refining sugar.

	Found.	Atoms.	Calculated.
C	34.27	8	34.39
H	6.51	9	6.32
N	19.84	2	19.92
O	39.38	7	39.37

When in combination with oxide of lead, it is found to have lost 2 equiv. of water, its composition being then $C^8 H^7 N^2 O^5 + 2\,Pb\,O$. With nitric acid it produces nitro-saccharic acid, $C^8 H^7 N^2 O^5 + 2\,N\,O^5 + 4\,Aq$.

The combination of a great portion of water with this primary substance in the animal body is especially remarkable; —in the formation, for example, of diabetes sugar, either from cane-sugar or from starch, in diabetes mellitis; and in the formation of milk-sugar, which, when crystallised, is represented by

$$2\,(C^{12}\,H^{12}\,O^{12}).$$

This latter is a kind of sugar which is found in milk, and which has an equivalent weight different from that of all the other kinds of sugar, with the exception of that from the Eucalyptus. Plants agree with animals in this respect, that both give the same impulse to the elements of cellulose, dextrin, starch, and sugars already produced, inducing the formation of more hydrated sugars.

The connexion which exists between cane-sugar and gelatine-sugar (a nitrogenous sort of sugar produced from gelatine by acids), affords reason for believing that all these complex substances, however different, have one or more primary compounds in common; and also that sugar—which is either supplied to animals as food, or is produced, during digestion, from cellulose, starch, or dextrin, substances so readily changeable into sugar by digestion,—belongs in reality to the constituents of the animal body. For it is probable that the gelatine-sugar is not actually produced, but is only separated from its combinations, by sulphuric acid. Thus, in animals, sugar is a component part of the gelatinous tissues; but, when separated from its state of combination in these tissues, it may perform the same function as when either cane or grape-sugar is supplied to the animal for food. In other words, there exists in the substances which yield gelatine a primary matter which exists also in cane-sugar. If, then, substances or tissues containing gelatine, are employed in effecting the change of materials which takes place in the animal, this primary matter may serve the same purpose as cane-sugar, when supplied to feed the body. For this reason, gelatine-sugar ought really to be classed among the nourishing substances.

If gelatine-sugar be in reality a compound of cane-sugar, in which 1 equivalent of urea has been substituted for 1

equivalent of water, it is highly probable that, when sugar is brought into the body as a feeding substance, it may there form numerous combinations, and may, therefore, by no means be destined merely to maintain the function of respiration. If gelatine be formed in the animal body, then sugar, either derived directly from the food, or produced from starch in the alimentary canal, may be used for this purpose.

In what part of plants the sugar is formed, we do not know. From the cells in which it has been formed, probably from dextrin, it is carried through the whole plant. In some parts it accumulates to a great extent, and is even here and there conveyed in considerable quantities to the exterior of the plant. Of the latter, we have instances in the nectaries, where we often see the sweet sap, after being concentrated by the evaporation of the water, exhibit a beautiful mass of crystals of sugar. When sugar accumulates in certain series of cells, it does not become an almost solid substance, as gum does, but remains in the state of a sap, though in some plants it is very concentrated. This is owing to its great solubility in water, and to the solution being constantly inclosed in the vessels or cells. If, therefore, we merely press the parts which contain sugar, and in this manner break the vessels or cell-walls, we obtain almost all the sugar—leaving but a very small quantity behind. From the birch and other trees, a saccharine sap exudes in spring, which, by fermentation, produces birch-wine. Knight states that this birch sap contains more sugar, the farther from the roots it is collected; this proves that the sap, rising from the root (which sap probably contains much dextrin) is changed into sugar as it passes through the cell-walls. It has recently been proposed to prepare sugar from the stalks of maize, before fructification has commenced, for then the stalk contains a great deal of sugar-sap.* The bleeding of the vine is a familiar appearance. In North America, sugar is also obtained from the maple, by boring in spring a hole through the bark into the wood. In this manner, 16 lbs. of liquid, having a density of 1.006 to 1.003, are obtained on an average every 24 hours, from a single opening,

* Pallas, Soubeiran, and Biot, in Comptes Rendus, 12 Septemb. 1842.

We are taught by general Chemistry, that to the true varieties of sugar belong those substances only, which contain hydrogen and oxygen, in the proportions which form water, and which can produce alcohol by fermentation. The production of mannite $C^6 H^7 O^6$, of glycyrrhizine $C^{16} H^{12} O^6$,* and of similar sweet substances, has no connection with the formation of sugar. They are probably produced in plants by the decomposition of cane or grape-sugar. Thus, for example, mannite is produced from beet sap, when it is fermented at a high temperature, and during the change of starch into grape sugar, by the action of sulphuric acid. According to Mitscherlich, even the Tamarix gallica, var. mannifera, Ehrenb.—a plant belonging to those which produce manna,—gives nothing but grape-sugar, containing no mannite whatever. It is almost certain, therefore, that mannite is a product, arising from the decomposition of grape-sugar, and that in those plants, from which manna is obtained, grape-sugar is formed first.

When cane-sugar is converted into mannite by fermentation, at an elevated temperature, lactic acid is at the same time produced; this acid being often called a component part of plants, though it is derived only from the decomposition of sugar. If beet-sap be exposed to a temperature of 86° to 104° Fahr., it begins to ferment, the cane-sugar is converted into grape-sugar, which, after some time, also disappears, mannite and lactic acid being found in its place, with a gummy substance besides, which has the same composition as gum arabic. The latter substance is remarkable, because it affords an instance of a retrograde formation of gum (dextrin ?) from sugar; which change, here an effect of art, probably often takes place in plants. For we frequently see that saccharine fruits lose their sweet taste and become mealy, as it is called. Nothing occurs in this case but a formation of cellulose, undoubtedly preceded by a change of sugar into dextrin, the quantity of sugar being diminished. (See p. 227.)

The gummy substance just mentioned, contains the elements of sugar; the change, therefore, is only an isomeric one. The mannite and the lactic acid are produced from

* Vogel in Erdmann und Marchand's Journal, Bd. 28, S. 1.

another part of the beet-sugar. If added together, however, they do not represent the formula of sugar. Thus—

		C	H	O
Lactic acid,	=	6	5	5
Mannite,	=	6	7	6
Sum,	=	12	12	11

To form grape-sugar, one equivalent of oxygen is wanting. This oxygen may have been taken from the produced grape-sugar by the protein compound in the sap, which has been drawn within the circle of action. For the fermented liquid contains ammonia; and therefore the protein existing there must have been decomposed. (Liebig.)

At all events, we here find the production of lactic acid—a chief constituent of the animal body—from sugar, by the influence of protein in a state of decomposition; for which reason we may suppose, that there is probably a similar production of it in the animal body. (See *Fats.*)

Equally remarkable is the production of butyric acid from sugar, by the influence of casein, as has been found by Pelouze and Gélis. (See *Milk.*)

E. Mucilage.

In various parts of plants a substance occurs, to which the name of mucilage is given—which, though insoluble in water, yet swells and expands, when immersed in it, assuming the appearance of a mucilaginous mass, which contracts again under the action of alcohol and metallic salts. It sometimes accumulates largely in certain parts of plants, as in the perisperm of quinceseed, lintseed, &c. When these seeds are soaked in cold water, this mucilage is expanded and so squeezed out. It is the chief constituent both of gum tragacanth, and of gum bassora. It occurs mixed with pure gummy matter in some natural kinds of gums, as in those of the plum and cherry trees. But whatever form it may assume, it has always the same composition, and the only difference among its varieties, is in their power of combining with certain proportions of bases.

The roots of Salep, Althæa (mallows), and Symphytum, abound in mucilage, and from the Ulva crispa, in which, it

exists in a peculiar form, it is obtained as a jelly by boiling in water.

I formerly considered this mucilage to be identical in composition with pectin; this opinion I derived from the result of the analyses which I made of its lead-compounds. It naturally contains, however, a large quantity of carbonate of lime; by which those lead-compounds were rendered impure, so as to cause an inaccurate determination of the hydrogen and carbon.

It has been shown by C. Schmidt (Annalen der Chemie und Pharmacie, July 1844), that mucilage is one of those bodies, which contain hydrogen and oxygen in the proportions to form water. The results which I obtained from the substances, precipitated by alcohol and hydrochloric acid, and perfectly dried before being subjected to analysis, differ by ½ equivalent of water from those of Schmidt. When dried at 302° Fahr., I find their composition to be represented by the formula, $C^{24} H^{19} O^{19}$, that is, to contain, when compared with starch, just as much less of water as cellulose contains more.* Schmidt makes it $C^{12} H^{10} O^{10}$, when dried at the temperature of 212°, 221°, 230°, and 248° Fahr., and when dried at 347° Fahr., he calls it $C^{12} H^{9} O^{9}$. It is, however, certain that mucilage, if exposed to a current of dry air at a temperature, increasing from 212° to 282° Fahr., is continually losing water, and that at 320° Fahr., it begins to be decomposed.

Whilst, therefore, we are indebted to Schmidt, for being made acquainted with the true character of mucilage, I nevertheless consider myself obliged to represent it by the formula, $C^{24} H^{19} O^{19}$.

* Mucilage from lint-seed.

	At 302° Fahr.
C	45.82
H	5.92
O	48.26

From quince-seed.

	At 302° Fahr.
C	46.20
H	6.03
O	47.77

From tragacanth.

	At 302° Fahr.
C	45.86
H	5.84
O	48.30

	Atoms.	Calculated.
C	24	46.14
H	19	5.98
O	19	47.88

* Annalen der Chemie und Pharmacie, Band III.

Schmidt has shown, that mucilage, when digested with dilute sulphuric acid, is changed into sugar. Hence it supplies a link in the following series of substances analogous to starch:—

Grape-sugar and fruit-sugar, ...	$C^{24} H^{24} O^{24}$
Cellulose and soluble inuline, ...	$C^{24} H^{21} O^{21}$
Starch, dextrin, and gum, Insoluble inuline and lichen-starch,	$C^{24} H^{20} O^{20}$
Mucilage, milk-sugar, and Eucalyptus sugar, ...	$C^{24} H^{19} O^{19}$
Cane-sugar, ...	$C^{24} H^{18} O^{18}$

Animal mucus. The product of the mucous membranes in the animal body has often been compared to mucilage. Though they really agree in some points, their character and composition entirely differ. Like mucilage, it does not dissolve when mixed with water, but merely remains suspended in it, so that it does not pass through the filter. When dried, it swells in water, like gum tragacanth or salep, and increases greatly in bulk. Hence, in its natural state, the animal mucus, like the mucilage of plants, is penetrated by the salts which exist both in animal and vegetable liquids.

It is owing to their character of insolubility that both these substances are fitted to cover denuded parts of animals; —that they are both suited to soften and to lessen the influence of acrid substances on the tender parts of the animal body. It is for this reason that the mucilage of salep, tragacanth, &c., may be made to supply the want of animal mucus.

These, however, are the only points of conformity between vegetable and animal mucus, and they are only physical. The latter contains nitrogen, and in this respect it wholly differs from the former. Its composition and properties are different also, according to the organs by which it has been produced.*

* We have, as yet, analyses of only three varieties of animal mucus, viz., 1° That of the oviduct of frogs, which has been called shooting-stars (*Sterre-Schot*). Scheik. Onderz. Deel I.

C	50.53	51.03
H	6.53	6.77
N	9.27	9.58
O	33.67	32.62

Thus, for instance, mucus from the gall-bladder can be precipitated from its alkaline solution by acids; that from the urinary-bladder is more or less soluble in acids; while that from the *primæ viæ* is soluble in alkalies, and precipitable by acids.

It is only in passing that I here mention animal mucus, because these really different substances have been confounded with each other, from the similarity of their names, and in consequence of their happening to possess some properties in common.

F. Pectin and Pectic Acid.

In several plants a substance has been found, different in composition from all those of which we have hitherto treated, and which constitute one common group. This substance is sometimes gelatinous and neutral, and then it is called *pectin*; sometimes it is gelatinous and acid, and then it has the name of *pectic acid*. Its composition is constant, and is represented by the formula $C^{12} H^{8} O^{10}$,* being thus really different from the cellulose series.

2* We know the composition of the mucus from the œsophagus of the swallows, which in India build their edible nests of it. (Bulletin, 1838, p.172.) The pure mucous matter, which I called *neossine*, consists of:—

	I.	II.	Atoms.	Calculated.
C	54.81	55.02	22	55.17
H	7.02	7.10	17	6.96
N	11.64	11.66	2	11.62
O	26.53	26.19	8	26.25

And V. we have analyses of the mucus from the gall-bladder of the ox by Kemp (Annalen der Pharmacie, Bd. 43, S. 118.)

C	52.54	52.25
H	7.95	7.83
N	14.33	14.84
O	25.18	25.08

It appears from this either that animal mucus is a variable mixture of heterogeneous substances, or that different substances at present bear the name of mucus in common.

* According to my experiments (Natuur-en Scheik. Archief, Deel V.), pectin from sweet apples consists of:—

				Atoms.	Calculated.
C	45.20	45.61	45.85	12	45.47
H	5.35	5.37	5.48	8	4.95
O	49.45	49.02	48.67	10	49.58

It is found in the state of pectin in fruits, for example, in apples, pears, quinces, cherries, plums, and currants. If boiled with sugar and water, these fruits become very gelatinous; the pectin being changed in form, and becoming probably a hydrate. It is not known which form it has in plants, and of what organs it constitutes a part. Pectin, however, is probably to be comprised in the series of the so-called incrusting matters (see p. 205). If fruits are boiled with an alkali, pectic acid is formed by the action of the alkali, the pectin being converted into pectic acid, which is polymeric with it. It can also be obtained from turnips, carrots, &c.

This pectin or pectic acid is also one of the more important kinds of food, but its elements must undergo, in the animal body, a change different from that which starch, dextrin, sugar, inuline, lichen-starch, or cellulose undergo,—since pectin and pectic acid do not contain hydrogen and oxygen in the proportions to form water.

All these substances, when combined with bases, give gelatinous salts, which exist in substances used for food; being either already present in the plants themselves, or being produced in them by boiling.

Experience has taught us, that these substances are of the greatest importance in the feeding of animals; but it is still quite unknown how they are so. We do not know what change they undergo in the animal body. Their relations to the structure and functions of plants are also evidently of

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Pectic acid:—

	From carrots (Daucus Carota.)		From turnips.	
C	45.48	45.47	45.41	45.36
H	5.39	5.27	5.20	4.98
O	49.13	49.26	49.39	49.66

Some of these substances have also been analysed by Regnault and Fremy. Regnault makes the formula of pectic acid $C^{24}H^{15}O^{22}$; Fremy, $C^{24}H^{17}O^{23}$. (Ann. der Pharmacie, Bd. 35, S. 322.) I therefore requested Fromberg to make a new examination of pectic acid; but he obtained the same results as I had. (Scheik. Onderz. Deel II.) Metapectic acid is polymeric with pectin, according to Fremy, who represents the three substances as follows:—

Pectin.	$C^{24}H^{17}O^{22} + RO$
Pectic acid.	$C^{24}H^{17}O^{22} + 2RO$
Metapectic acid.	$C^{24}H^{17}O^{22} + 5RO$

great importance, seeing that they exist in almost all plants, and sometimes to a considerable extent.

Pectin is one of those substances by which the cell-walls are incrusted. In fruits it is produced during ripening in large quantities; before that period, it occurs but sparingly. During the ripening of fruits, the appearance of the cell-walls changes very much; from opaque and solid they become semi-transparent and loose. Fremy states (Annal. der Pharmac. Bd. 37, S. 339,) that pectin is produced in fruits by the influence of the acids, which the fruits when unripe contain; for unripe fruits, if boiled with water only, gave no pectin; but if boiled with tartaric, malic, or sulphuric acids, a large quantity of pectin appeared in the liquid. This is an important observation. We are taught by it, that as this property of producing pectin by the action of acids is not possessed by the common incrusting matter (woody matter), the unripe fruits must contain another substance, with which the cell-walls are thickened. A similar one must also exist in carrots, turnips, and other plants producing pectin. The formation of this acid in fruits is attended by the production of sugar also, and at the same time, the acid contained in the unripe fruit disappears; for we observe, that while fruits are ripening, pectin and sugar simultaneously increase.

In fruits and other parts of plants, therefore, pectin exists in a solid state, deposited upon and within the cell-walls. If these fruits are boiled with an alkali, pectin is dissolved, and the cell-walls remain. At the same time, however, the pectin is changed into pectic acid—a very gelatinous substance, which readily combines with bases to form jellies. If the boiling with alkali is continued for a long time, the jelly disappears, and we obtain an acid soluble in water, and [illegible] in other acids which Fremy has called *meta-pectic acid*. [illegible] that, when combined with bases, it had the same composition as the pectic acid.*

* Notwithstanding the numerous researches of Mulder and others, mentioned in the text, the subject of pectin is still far from being cleared up. [illegible] lately published a paper (Annalen der Pharmacie, li. p. 355) on [illegible] containing the results of a series of analyses which have led him to

G. Extractive Matters.

In approaching this head, we cannot but express our regret, that so many gaps remain to be supplied in science. It includes very different substances, and may be compared to the old *schorl-class* among minerals. The class of extractive mat-

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results differing from all those hitherto published. I shall here insert a brief abstract of them :—

1° *Pectin* precipitated by alcohol from the sap of the pear or apple, left 6 to 8 per cent. of ash, and gave, by burning, 46.03 carbon, and 5.50 hydrogen. The same pectin after solution in water, slightly acidifying with muriatic acid to separate the bases, and again precipitating by alcohol, left only 1.59 per cent. of ash, and gave 43.74 carbon, and 5.52 of hydrogen. It is not impossible that by this treatment the pectin may have been changed.

2° *Pectic acid*, obtained by boiling the rasped and washed white turnip in dilute caustic potash, filtering and precipitating by muriatic or nitric acid, left 0.5 per cent. of ash, and gave 42.22 of carbon, and 5.17 of hydrogen.

3° *Pectous acid* is obtained by boiling the rasped and washed turnip in dilute muriatic acid, and precipitating the filtered solution by alcohol. It left 0.86 of ash, and gave 43.18 of carbon, and 5.59 of hydrogen. Chodnew considers this acid to exist ready formed in the turnip, and to be in combination with the earthy bases it contains.

4° The *per-pectic acid* is obtained by washing well what the dilute muriatic acid leaves undissolved (3°) then boiling it in caustic potash, and precipitating by an acid. If ammonia be used instead of potash, nothing is extracted; this acid therefore is not produced by the action of ammonia, or if present is insoluble in it. The dried acid left 0.52 of ash, and gave 41.45 of carbon, and 4.83 of hydrogen.

5° *Meta-pectic acid.* On boiling pectic acid in dilute caustic potash, neutralising the solution by acetic acid, and precipitating by acetate of lead, a salt is obtained; the composition of which is the same as that of the similar salt of pectic acid.

6° *The fibre of the fruit*, or turnip, is obtained by washing the rasped fruit or turnip well with water, then extracting it with alcohol and ether, but not acting upon it with acids or alkalies. From turnips it left 1.78 of ash, and from apples 0.56, and gave 45.90 of carbon, and 6.27 of hydrogen. After boiling with caustic potash, the composition was found by Chodnew to be unchanged, from which he infers that the proportions of pectous and meta-pectic acid in the turnip must be very small. This conclusion of Chodnew appears to me to be very doubtful, and to throw a shade of uncertainty upon his other results, since Fromberg found in my laboratory that diluted caustic and carbonated alkalies extracted as much as was equivalent to 10 per cent. of the dried substance of the turnip.

Chodnew's experimental and calculated results, are as follows :—

ters is enough to satisfy any one, who would arrange organic nature according to simple principles, of the very limited knowledge we possess in regard to what takes place within the interior of plants.

It is but a few years since the amorphous substances of the organic kingdom ceased to be considered by many as unworthy of investigation. This is still the case with the extractive matters. It is only by unprejudiced men, like Berzelius, that their great importance in the organic kingdom

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	Fibre.		Pectin.		Pectous acid.	
	Experiment.	Calculated.	Exper.	Calcul.	Exper.	Calcul.
C	45.90	45.90	43.74	44.09	43.18	43.18
H	6.27	6.01	5.52	5.51	5.59	5.39

	Pectic acid.		Per-pectic acid.	
	Experiment.	Calculated.	Experiment.	Calculated.
C	42.22	42.42	41.45	41.68
H	5.17	5.05	4.83	4.17

His formulæ are :—

Fibre of the fruit, ...	$C^{36}H^{22}O^{22}$
Pectin, ...	$C^{36}H^{21}O^{24}$
Pectous acid, ...	$C^{36}H^{21}O^{25}$
Pectic acid, ...	$C^{36}H^{20}O^{22}$
Per-pectic acid, ...	$C^{36}H^{19}O^{27}$

And he states further :—

a. That pectic acid is very sparingly soluble in water, but dissolves readily in caustic potash and *ammonia*.

b. That pectous acid dissolves readily in water.

c. That per-pectic acid dissolves in caustic potash, but *not in caustic ammonia*.

d. That the pectous acid is the only one of these acids that exists ready formed in the turnip—that it exists there in combination with lime, which dilute muriatic acid extracts in the cold, rendering the turnip transparent, and leaving the pectous acid soluble in water.

e. That pectous acid is changed into the pectic by the action of caustic potash.

f. And that the pectic is changed into sugar, by the action of acids. In the turnip, he supposes the pectous acid to be the source of the sugar; and in ripe fruits, that one of the functions of the other acids, such as the malic and tartaric, which they contain, is to promote the transformation of the pectic and analogous acids into sugar during the process of ripening.

This paper of Chodnew's adds considerably to our knowledge, but a repetition of his researches will, I am satisfied, lead to considerable modification of his results.—*J*.

is appreciated, although they are destitute of any crystallised form. It is incomparably more difficult to investigate these substances than the crystallisable ones; but this is not a reason why they should be deemed as less important.

A general idea of extractive matters has been derived from this, that in medicines known by the name of extracts, a substance has been found soluble in water and alcohol, and which, assuming a brown colour during evaporation, leaves a coherent mass of a dark colour behind. This substance has been called *soapy matter* by Scheele. In the plant it is colourless, but when exposed to heat and air, it is changed into apotheme, and acquires a brown colour.

We cannot give any certain account of the transformations of vegetable substances, until these extractive matters of plants are sufficiently known. In herbaceous and in non-herbaceous plants, they are found to be of nearly the same character. Perhaps it is always the same substance, modified by an admixture, in different proportions, of dextrin, sugar, inuline, &c. But we know neither the character nor the composition of this compound, and since it is universally diffused —always present in vegetable saps—much remains as to which we are still quite in the dark.*

We are equally ignorant as to animal extractive matters. They are substances to which the same name has been given, on account of their brown colour and their solubility in water and alcohol. This name, however, can have no other effect, than to keep us longer in a state of ignorance on the subject. With infinite zeal and labour, Berzelius has succeeded in decomposing a great many animal substances, which were known by the name of extractive matters. Since he has pointed out the right way of investigation, we may expect that ere long we may obtain some useful knowledge on this branch of enquiry. We must now limit ourselves to the acknowledgment, that, of these undoubtedly highly important substances in the animal organs, we cannot form any clear idea. I only allude,

* The fancy of Hermann (Erdmann und Marchand's Journal, Bd. 28, S. 53), that extracts consist chiefly of humic, crenic, and apocrenic acids,—in a word, of the chief constituents of the soil is too singular to be dwelt upon.

therefore, to this large class of bodies, consisting, perhaps, of hundreds of different compounds, that I may not conceal our ignorance by saying nothing. We know nothing about the composition of these substances or their transformations, and so we pass them by.

H. Fats.

Both in plants and animals a peculiar series of substances occurs, which we call fats. The effects they are destined to accomplish in the animal body, are the reverse of those which they accomplish in plants; for they are consumed by animals, and, on the contrary, are prepared by plants. Hence, their production in plants must be caused by an opposite action from that, by which they are worked up and converted into other substances by animals.

Most of these fats were formerly considered as salts of fatty acids with glycerine. According to this view, whenever a neutral fatty body is produced in plants, a fatty acid and glycerine must have been previously produced; and on the other hand, as often as, in animals, a neutral fat is worked up, both a fatty acid and glycerine may be employed in the change of materials which takes place. Since, however, we know that glycerine is not the base of neutral fats, but is only produced during their change into soaps, we must modify these conclusions. This modification, however, is limited to the combination or separation of water.

These neutral fats are, for the most part, combinations of two different ones. Plants contain a mixture of margarine and elaine in their fat oils, such as olive oil, &c. Animals contain the same mixture, but in other proportions, as in human fat, hog's-lard, &c.; while in the fat of the sheep and other animals, we find a large quantity of stearine, combined with the margarine.

Stearine, margarine, and elaine are the most generally diffused fatty substances in the organic kingdom; but they are not the only ones. There are, on the contrary, a great many other substances, also fatty and neutral, which are found in determinate parts of plants or in peculiar organs of the animal body.

We intend briefly to consider their composition, as it is now generally assumed; first, however, we would say something of glycerine.

1° Glycerine is a substance readily soluble in water, having a sweet taste, and appearing like a syrup. It is obtained by combining one of the neutral fats with a powerful base into a soap; when a fatty acid combines with the base, and glycerine is set free. The composition of glycerine was long supposed to be,—

$$C^6 H^8 O^6$$

But Stenhouse has found that it is,—

$$C^3 H^2 + O$$

—this formula being deduced from the analysis of some neutral fats, not generally diffused through plants. Recently, glycerine has again been analysed by Redtenbacher, and he found:—

$$C^6 H^4 O^2 + 4\,HO$$

This composition agrees completely with that found by Stenhouse, while it also accords with the previous analysis of Pelouze. Redtenbacher represents glycerine as a kind of alcohol, produced during the formation of soap. The matter $C^6 H^4 O^2$, which he has called *acroleïne*, is analogous to *aldehyd*, in so far as it produces, by oxidation, acrylic acid, $C^6 H^3 O^3$, which has many properties in common with acetic acid. Like aldehyd, acroleïne is very easily converted into a neutral, crystallisable substance.

Berzelius thinks that glycerine does not exist ready formed in the neutral fats, but that it is a product of the formation of soap; and he considers the base of the neutral fats to be an oxide of a radical, which he calls *lipyle*, represented by the formula, $C^3 H^2$, and its oxide by that of $C^3 H^2 O$. Glycerine is thus formed from 2 equiv. of this oxide, with 3 equiv. of water:—

$$2 \times C^3 H^2 O + 3\,HO = C^6 H^7 O^5 *$$

* Redtenbacher, in Ann. der Chem. und Pharm. Aug. 1843. Letter from Berzelius, 2d June 1843.

The base of all neutral fats, containing glycerine, is, therefore, a compound the formula of which is $C^3 H^2 O$. Hence, when neutral fats are produced in plants, together with the fatty acids, this base must be formed, and when neutral fats are consumed in animals, this base must be consumed also.

2° The most important of the fatty acids are the following:—

Stearic acid, ...	$C^{68} H^{68} O^5 + HO$
Margaric acid, ...	$C^{34} H^{34} O^3 + HO$
Elaïc acid, ...	$C^{44} H^{40} O^4 + HO$ *

They are universally diffused in plants and animals. When combined with $C^3 H^2 O$, they form stearine, margarine, elaïne, or the neutral fats. In this neutral state they usually occur in plants and animals. It sometimes happens, however, that, by the influence of powerful bases, $C^3 H^2 O$ is separated in the organic kingdom, and thus compounds of fatty acids with soda, &c., are produced.

The other fatty acids, at present known, are:—

* Redtenbacher and Varrentrap, by whom these acids were last analysed, gave the following formulæ:—

Stearic acid, ...	$C^{36} H^{36} O^3 + HO$
Margaric acid, ...	$C^{34} H^{33} O^3 + HO$
Elaïc acid, ...	$C^{44} H^{39} O^4 + HO$

But Berzelius has remarked, that the analyses agree better with the formulæ mentioned in the text, as shown by the following comparison of the calculated and experimental results.

a. Stearic acid of Redtenbacher.

	Found.	Atoms.	Calculated.
C	76.53	68	76.76
H	12.93	69	12.90
O	10.52	6	10.34

b. Margaric acid of Redtenbacher.

	Found.	Atoms.	Calculated.
C	75.64	34	75.64
H	12.86	35	12.71
O	11.50	4	11.65

c. Elaïc acid of Varrentrap.

	Found.	Atoms.	Calculated.
C	76.73	44	76.89
H	11.89	41	11.69
O	11.38	5	11.42

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Cocinic acid, ... $C^{27} H^{27} O^3 + HO$
produced by forming cocoa butter into a soap.*

Myristic acid, ... $C^{28} H^{28} O^3 + HO$
by forming a soap of nutmeg butter, of which it constitutes the greater part; being, however, combined with two other fatty substances besides.†

Palmitic acid, ... $C^{32} H^{32} O^3 + HO$
by forming palm oil soap.‡

Lauro-stearic acid, ... $C^{24} H^{23} O^3$
by forming a soap of laurel oil.§

We shall first treat of those fatty acids, which are found in plants.

When salad oil is conveyed into the stomach, it may pass unchanged into human fat; for both consist of margarine and elaïne, though in different proportions. Now, as margarine and elaïne are found in a great many vegetables which are used for food, nothing is more simple than to assume a transference of these substances from vegetable food into the fats of the animal body.

* Cocinic acid. Bromeis.

	Found.	Atoms.	Calculated.
C	73.39	27	73.36
H	12.37	28	12.42
O	14.24	4	14.22

Berzelius, ibidem, S. 311. Bromeis makes its formula $C^{27} H^{27} O^4$.

† Myristic acid. Playfair. Ann. der Chem. und Pharm. Bd. 38, S. 152.

	Found.	Atoms.	Calculated.
C	74.06	28	73.75
H	12.29	29	12.54
O	13.65	4	13.71

Playfair makes it $C^{28} H^{27} O^3 + HO$.

‡ Palmitic acid. Stenhouse.

	Found.	Atoms.	Calculated.
C	75.48	32	75.08
H	12.41	33	12.64
O	12.11	4	12.28

Stenhouse calculates it according to the formula, $C^{32} H^{31} O^3 + HO$.

§ Marsson, Annal. der Chem. und Pharm. Bd. 41, S. 334.

	Atoms.	Calculated.
C	24	75.61
H	23	11.92
O	3	12.47

But if food of this kind, containing margarine and elaïne, be eaten by a sheep, these substances must undergo some chemical alteration in the body of the animal, since mutton fat contains stearine in abundance. As to margarine, this change is very simple. If we neglect the glycerine, it is represented in the following manner:—

From 2 equiv. margaric acid,	... ...	$C^{68}\ H^{68}\ O^{6}$
Take 1 equiv. stearic acid,	... ...	$C^{68}\ H^{68}\ O^{5}$
There remains	... ...	O^{1}

Thus from 2 equivalents of margaric acid, 1 equiv. of stearic acid is produced, and 1 equiv. of oxygen is given off. It is highly probable, that such a deoxidation of the margaric acid in the food of the sheep is really effected; and that, on the other hand, when mutton fat is used for food by man, stearic acid is converted into margaric acid, by the absorption of oxygen.

Although the fatty acids may thus easily be transformed into each other, yet when stearine is converted into margarine, a portion of oxide of lipyle is wanting. The one half of the stearine combining with half an equivalent of oxygen, and with the whole of the oxide of lipyle present, is changed into margarine—the other half remains as stearic acid.* Hence when a man eats mutton fat, one of three things must happen—either some oxide of lipyle must be produced in his body—or glycerine must be present, which, under certain conditions, combines with stearic acid and ½ equiv. of oxygen to form margarine—or (and this is the more probable supposition) the half of the stearic acid must be applied in the animal body to other purposes.

* The statement of the text becomes clearer when put in this form:—

	Stearic Acid.		Oxide of Lipyle.
Stearine consists of	$C^{68}\ H^{68}\ O^{5}$	+	$C^{3}\ H^{2}\ O$
Add ½ O	$O_{\frac{1}{2}}$		
And we have	$C^{68}\ H^{68}\ O^{5\frac{1}{2}}$	+	$C^{3}\ H^{2}\ O$
Deduct one of margarine.	$C^{34}\ H^{34}\ O^{3}$	+	$C^{3}\ H^{2}\ O$
And ½ of stearic acid remains,	$C^{34}\ H^{34}\ O^{2\frac{1}{2}}$		

The stearic acid has no oxide of lipyle with which it can combine to form neutral stearine, and hence the consequences stated in the text.—J.

The fats of the goat, the cow, the horse, the pig, and the goose, all contain more or less stearine, mixed with margarine and elaïne. Human fat is free from stearine. When margarine and elaïne, the common fats in plants, are converted into the fat of one of these animals; or when the fat of one animal is converted into that of another,—in all these cases such a change as that we have above indicated must take place.

Elaïc acid is an anomalous acid. Those which we have as yet mentioned, are all oxides of a carbo-hydrogen. Elaïc acid is an exception. It may be considered as a carburetted hydrogen ($C^{44} H^{44}$), in which four equivalents of oxygen have been substituted for four of hydrogen.

$$C^{44} H^{44} + O^4 - H^4 = C^{44} H^{40} O^4$$

But it is more probably a complex substance,—for when it is converted into elaïdic acid by the action of nitrous acid, another fat acid is at the same time produced, which has a dark red colour.* Also when it is melted with potash in excess, the product is a peculiar acid, represented by $C^{32} H^{30} O^3$, and the remainder, $C^{12} H^9 + HO$, forms 3 equiv. of acetic acid, by absorption of oxygen from the air. Thus:—

From elaïc acid, ...	$C^{44} H^{40} O^4$
Take the acid, ...	$C^{32} H^{30} O^3$
And there remain, ...	$C^{12} H^{10} O$ †
Add 9 of oxygen from the air, ...	O^9
And we have, ...	$C^{12} H^{10} O^{10}$

Which are equal to—

Three of vinegar, ...	$C^{12} H^9 O^9$
And one of water, ...	$H O$
	$C^{12} H^{10} O^{10}$

We have thus strong grounds for regarding elaïc acid as a compound of two substances at least.

* Meyer, in Annal. der Chem. und Pharmacie, Bd. 35, p. 174.

† Varrentrap, ibidem, p. 210.

When elaïne, either in the form of vegetable or animal food, is eaten by animals, the fats of which contain margarine and elaïne, it may or may not be converted into margarine. We do not know of any experiments, which could at all decide this. If we commence with elaïc acid, leaving out of view the oxide of lipyle—only a portion of its constituent elements is employed, when the supposed change of elaïc into margaric acid takes place. Thus:—

From elaïc acid, ...	$C^{44}\ H^{40}\ O^4$
Take margaric acid, ...	$C^{34}\ H^{34}\ O^3$
There remain,	$C^{10}\ H^6\ O$

Hence, when elaïne is changed into margarine, $C^{10}\ H^6\ O$ are set free. Now, there exists a substance, having many properties in common with benzoic acid, viz., *sebacic acid*, $C^{10}\ H^8\ O^3$, differing from the last-mentioned formula only by two equivalents of water. This acid has not been artificially prepared from stearic or margaric acid, but it is obtained from elaïc acid by sublimation. Not a trace of it, however, has yet been found in the animal body. It is, therefore, quite unknown at present, to what purpose these elements, $C^{10}\ H^6\ O$, are applied.

It is improbable that stearine, in the animal body, is converted into elaïne, as well as into margarine.

When either vegetable or animal fat is brought into the body of an animal, through the substances used for food, it may be a question, whether or not the neutral fat be taken up unchanged, and deposited in the cellular tissue? When, for instance, a man eats margarine and elaïne, we may ask—Are these neutral fats taken up by the body unchanged? Or are they first saponified, so as to circulate in the state of fatty acids, and then again brought back to the state of neutral fats by uniting with oxide of lipyle, previously existing in the body? If the latter be impossible, it is equally impossible, that fatty acids existing in the food should ever be converted into neutral fats in the body.

It may be assumed, with some degree of probability, that neutral fats enter into the blood not unchanged, but saponified.

The alkaline character of the gall, when poured into the duodenum, and generally also of the chyle, render it impossible that fat should enter into the blood without being saponified. If it is saponified, we at once understand how compounds of fatty acids and soda should exist in the blood, and in many parts of the body. Oxide of lipyle must then be liberated, and changed into glycerine by taking up water. When, then, a soda-soap,—in man, for instance, margarate and eleate of soda,—exists in the blood, no production of margarine or elaïne from it can take place in the cellular tissue, without the access of glycerine; and the question is, whether this substance—a compound of oxide of lipyle and water—can, in the body, again produce neutral fats, by combining with the fatty acids?

We may safely answer this question in the negative. Glycerine would not combine with fatty acids into neutral fats. But the oxide of lipyle, in the nascent state, may combine with fatty acids into neutral fats, which may be deposited in the cellular tissue. It is in this way, that margarine and elaïne are produced from the margarate and eleate of soda, existing in the blood—for there exists in the body an important source of an oxide of the same radical—lipyle—which exists in glycerine.

We have seen (p. 248), that glycerine contains the protoxide of a radical, $C^3 H^2$, called lipyle. The second oxide of this radical exists in lactic acid. When lactic acid is sublimed, a white sublimate is obtained,

The composition of which is $= C^3 H^2 O^2$
That of oxide of lipyle being $= C^3 H^2 O$

When this sublimate is placed in contact with water, it is changed into lactic acid, 1 equivalent of water being taken up by 2 equivalents of the sublimate. For lactic acid consists of $C^6 H^5 O^5$.

Now, it is known, that lactic acid is frequently formed in the body. This point has been illustrated in a very striking manner, especially by Lehmann, in some experiments, which will be mentioned at the end of this section. It may happen, that causes of deoxidation are at work, by which certain

substances usually converted into lactic acid, are made to produce oxide of lipyle; and in this way, neutral fats may be produced from fatty acids, and this oxide of lipyle, while in the nascent state. For this reason, we think it probable that neutral fats—for instance, salad-oil—are not deposited directly and unchanged in the cellular tissue of man, but that they are first saponified, and that afterwards the margarate and eleate of soda from the blood are again reduced to neutral fats, by the influence of the lactic acid.

As to the other fats of plants, which we have mentioned above (p. 250), and numerous fats besides, of which we have as yet no knowledge, we cannot have any idea how they act in the animal body. It is known that cocoa-butter makes a man fat; it contains stearine. What, therefore, we have stated as to the transformation of stearine into margarine, is applicable to this case. Cocoa-fat, palm-oil, and nutmeg butter, of which the acids have already been mentioned (p. 250), are not so easily changed. It ought, however, to be remarked, that, like stearic and margaric acids, they are also oxides of a carbo-hydrogen (C H); and hence Dumas has been induced to make the following comparison among the known fatty acids of plants and animals. I give this comparison just as it has been given by Dumas, taking the hydrates of the acids. The composition of some of them he has modified after his own ideas, and these I shall mark with an interrogation.

His starting point is margaric acid, and, by subtracting from each acid successively $C^2 H^2$, he finds the following series of 17 substances, 9 of which are known.*

$C^{34} H^{34} O^4$ margaric acid
$C^{32} H^{32} O^4$ æthalic acid
$C^{30} H^{30} O^4$
$C^{28} H^{28} O^4$ myristicinic acid
$C^{26} H^{26} O^4$ cocinic acid (?)
$C^{24} H^{24} O^4$ laurinic acid
$C^{22} H^{22} O^4$
$C^{20} H^{20} O^4$
$C^{18} H^{18} O^4$ caprinic acid (?)

* Comptes Rendus, Tome 15, p. 935, 1842.

$C^{16}\ H^{16}\ O^4$
$C^{14}\ H^{14}\ O^4$ œnanthylic acid
$C^{12}\ H^{12}\ O^4$ capronic acid
$C^{10}\ H^{10}\ O^4$ valerianic acid
$C^8\ H^8\ O^4$ butyric acid
$C^6\ H^6\ O^4$
$C^4\ H^4\ O^4$ acetic acid
$C^2\ H^2\ O^4$ formic acid

The further we descend in this series, the more easily can the acids be fused. They all contain C H, or some other carburetted hydrogen, polymeric with olefiant-gas, as previously supposed by Chevreul.

3° In a great many parts of plants, especially in the perisperms of some fruits, a fatty substance is found, which can be prepared from sugar by a peculiar species of animal. This is wax. It has long been known to exist in plants; but it has only lately been shown, that bees can prepare it from honey, which does not contain any wax at all.

On the exterior part of many plants, we find several kinds of wax. It constitutes the purple bloom of grapes and plums. It may be abundantly procured from the skins of apples; and it is one of the component parts of the mixture which is usually called chlorophyle. Straw contains a crystallisable kind of wax; and a crystalline wax, which may be abundantly collected from the surface of sugar-cane, has been described by Avequin.

Many of these substances are oxides of a carburetted hydrogen. Van der Vliet found the formula for

Myricine, ... $C^{20}\ H^{20}\ O$
Cerine, ... $C^{10}\ H^{10}\ O$*

The latter is soluble in boiling alcohol, the former is not;—they are both constituents of ordinary wax.

* Bulletin, 1838, p. 134.

Myricine.	Found.	Atoms.	Calculated.
C	80.60	20	81.38
H	13.11	20	13.28
O	6.29	1	5.34
Cerine.	**Found.**	**Atoms.**	**Calculated.**
C	77.89	10	77.27
H	12.97	10	12.62
O	9.14	1	10.11

The formula, which Avequin found for the wax from the sugar-cane (Cerosia), is

$$C^{48}\,H^{50}\,O^{2}=48\,(CH)+2HO.^{*}$$

Avequin mentions an important peculiarity relative to this wax, namely, that such kinds of sugar-cane as contain much sugar, have but little of this wax; and, on the contrary, that such as give much wax, do not contain much sugar. This would seem to imply, that either wax is used in the plant, to produce sugar, or sugar to produce wax. The latter has been shown to be true in a very remarkable way, and one through which we obtain a glimmering of a general law, regulating chemical transformations both in plants and in animals.

It is very natural, that bees should simply collect the wax which exists in plants, ready formed. And it does so exist in plants. It can be abundantly extracted from the Myrica cerifera, but it exists along with honey, in all flowers visited by bees. This, therefore, is not the mode of ascertaining, whether both grape-sugar and wax are extracted from plants, or whether only the former is extracted, while the latter is prepared by the bees. It has, however, been positively proved by Gundlach,† that wax can be prepared by bees from sugar. He fed bees with a solution of sugar-candy in water, and saw them producing wax. He observed, further, that bees require twenty pounds of honey to produce one pound of wax.‡ Thus, sugar-cane and bees are both enabled to convert sugar into wax, that is, into a fatty substance. (See, below, the section upon *Chlorophyle.*)

¶ There are some animals, just as there are some plants, that contain peculiar fats. There are even separate organs, in which peculiar fats are found. We shall briefly enumerate these, as far as they are known.

* Ann de Chim. et de Phys., Octob. 1840, p. 218.

	Found.	Atoms.	Calculated.
C	81.4	40	81.4
H	14.2	50	14.1
O	4.4	2	4.5

† Naturgeschichte der Bienen. Cassel, 1842.

‡ This calculation can by no means be regarded as quite accurate, because honey always contains some wax, unless purposely purified beforehand.

In butter we find. principally in combination with oxide of lipyle (besides margaric and elaïc acids), also

	Caprinic acid, ...	$C^{18} H^{14\frac{1}{2}} O^{3}$*
	Capronic acid, ...	$C^{12} H^{9\frac{1}{2}} O^{3}$†
	Butyric acid, ...	$C^{8} H^{7} O^{4}$‡
and	Eleo-butyric acid, ...	$C^{34} H^{30} O^{4} + H O$

According to Berzelius, urine contains free butyric acid; according to Gmelin, it is also present in the gastric juice, and in the perspiration from the skin.

The following fatty substances are most probably produced in the animal body itself.

Cetine, in the Physeter macro-cephalus,—in a certain part of the cavity of the brain :—

* Chevreul.

		Calculated.
C	18	74.10
H	14½	9.74
O	3	16.16

† Chevreul.

		Calculated.
C	12	68.67
H	9½	8.87
O	3	22.46

‡ Butyric acid, de Jong. Scheik. Onderz. D. 1, p. 429.

	Found.	Atoms.	Calculated.
C	30.00	8	29.75
H	4.38	7	4.25
O	18.04	4	19.46
Ba O	46.58	1	46.54

See also Bromeis, in Annal. der Chem. und Pharmac. Bd. 42, S. 66.

The eleo-butyric acid of Bromeis, prepared from butter, is,—

	Found.	Atoms.	Calculated.
C	74.41	34	74.55
H	11.96	31	11.10
O	13.63	5	14.35

The composition comes very near that of margaric acid, $C^{34} H^{35} O^{4}$.

Thus it seems, that eleo-butyric acid is produced by the oxidation of margaric acid, and that it may, by deoxidation, be the source of the latter. Thus when the margaric acid, contained in the cow's fat, is converted into this eleo-butyric acid, 5 equivalents of oxygen are absorbed; on the contrary, when the eleo-butyric acid from butter used by man for food, is changed into margaric acid, 5 equiv. of oxygen are liberated. The greater part of butter-fat, however, is margarine, mixed with only a little butter-elaine.

$$C^{236}\ H^{232}\ O^{14}$$

This cetine contains margaric acid, elaïc acid, and ethal:—

$$C^{96}\ H^{99}\ O^{3} = 3\ (C^{32}\ H^{33}\ O) = 3 \times 32\ (C\ H) + H\ O + O^{2}$$

Phocenine, in the fat of Delphinus phocena:—

$$C^{26}\ H^{24}\ O^{12}$$

Cholesterine, in the gall and gallstones, in the blood, in the fats of the brain, in Fungus medullaris, in diseases of the ovaries and testicles:—

$$C^{37}\ H^{32}\ O$$

Ambranine, in amber:—

$$C^{33}\ H^{32\frac{1}{2}}\ O\ (H^{33}?)$$

Finally, the brain contains several fats, which have been investigated by various chemists—(Couërbe, Fremy);—fats, which, as they state, contain phosphorus and sulphur. These are named respectively by Couërbe, *eleëncephol, cerebrot, cephalot, stearoconot*. Their composition, however, is not yet sufficiently known.

5 This brief enumeration of the fats which exist in plants and animals, shows that the knowledge of their constitution is of great importance in reference to that of the change of materials in animals. Such fats are very generally found in plants, so that they appear, at least in small quantities, in every analysis of the parts of plants; but in seeds they are often found largely accumulated. When we find solid protein compounds deposited in plants, we often find also a great quantity of fat at the same time. This connexion between protein and fat is also remarkable in the animal body. The brain, which consists principally of albumen, contains a large quantity of fat. Milk, of which the chief constituent is a compound of protein, is likewise very rich in fat. But, on the other hand, in animals, fat is accumulated in the cells of the cellular tissue, occasionally to a very large extent, independently of any protein compound at all.

From what has been stated above, it is clear that animals receive much fat through the means of plants. Hence, the question has been discussed whether all the fat that animals possess, originates in plants. Dumas thinks it does, while Liebig asserts the contrary.* On this point, we have an im-

* Annal der Pharmac. und Chemie, Bd. 45

portant proof in the case of the bee. But the experiments brought forward by Dumas were so striking, that it appeared at first as if a cow drew really all the fat, contained in the milk, from her food.*

Without inquiring, whether the peculiar nature of the fat contained in nutritive substances had any influence on the production of fat in animals, it has been usual to consider all fats as of one kind, without attempting to determine their nature. It was determined how much fat could be extracted from the food by ether; how much food had been consumed by an animal in a given time; then the increase in weight of the full-grown animal by the use of this food;—and it was thought that such experiments were sufficient to decide, either that all the fat secreted by the animal exists ready formed in the food, or that part of it can be prepared from other substances, such as starch, sugar, &c. The goose was the animal in regard to which the dispute originated. When fattened with Indian corn, the starch of the corn must, according to Liebig, have been changed into fat, because he had found but a minute quantity of fat, one-tenth of a per cent., in that kind of grain. Dumas, however, extracted 9 per cent. of fat from Indian corn, and thus he found in the food which the goose had eaten in a given time, much more fat than the increase in the weight of the goose amounted to. It has since been shown, that Indian corn contains a very variable proportion of fat, and, therefore, that no conclusion can be drawn from this experiment.

It is not easy to resolve, in a satisfactory manner, the question which has been proposed, for almost every nourishing substance contains more or less fat. Liebig, however, quotes many examples of substances, which, although they are well known to be especially fit for fattening the animal body, yet contain little or no fat. All farinaceous substances,—rice, peas, beans, potatoes and corn,—are used, by preference, to fatten animals. Though they all contain fat, it is only in small

* Comptes Rendus, 6 Mars, 1843, p. 552. A long statement by Dumas, Boussingault and Payen, concerning the origin of fat in animals, may be seen in Comptes Rendus, 13 Ferrier, 1843, p. 345.

quantity. Rice gives 0.2 to 0.8 per cent. of matters soluble in ether; peas, 1.20 to 2.1; beans, 0.70; pressed beets, 0.67; dried potatoes, 0.35 per cent. Thus, any animal that has eaten 1000 pounds of one of these substances, may obtain from them, 2 to 8, 12 to 21, 7, 6¼, or 3½ pounds of fat respectively.*

Liebig states, that three pigs, to be fattened in 13 weeks, require 1000 pounds of peas, and 6825 pounds of boiled potatoes; the latter being equal to 1638 pounds of dry potatoes. These contain together 26 pounds of fat, 21 pounds in the peas, and 5 pounds in the potatoes. One fattened pig gives, on an average, 50 to 55 pounds of fat,—that is, the three together, 150 to 165 pounds. Each pig, before being fattened, contains, on an average, 18 pounds of fat,—that is, 54 pounds for the three. If to these 54 pounds we add 26 pounds from the food, we get 80 pounds, and if we subtract these from 150 to 165 pounds, there is a remainder of 70 to 85 pounds of fat, produced from the starch, &c., contained in the food.

To these results, Liebig adds some determinations of the fat existing in the excrements of the cow, the quantity of this being little different from what is found in the hay and potatoes, which a milch cow requires for food. Thus it would again follow from this, that the whole quantity of butter, supplied by a milch cow, fed upon hay and potatoes, is made up from the starch and other constituents of the food, not being drawn directly from the food in the state of fat. For a cow requires every day 15 pounds of hay, in which are contained 1.56 per cent. of fat = 1624 grains; and 30 pounds of potatoes, which contain 140 grains of fat, together 1764 grains. The excrements of a cow, every day, weigh nearly 8 pounds, containing 3.119 per cent. of fat, equal to 1750 grains, that is, about as much as the hay and potatoes contain together.†

In opposition to these experiments mentioned by Liebig,

* A fuller statement of the proportions of fat in our common crops, will be found in Johnston's *Elements of Agricultural Chemistry and Geology*, fourth edition, p 235.

† Comptes Rendus, 13 Mars, p. 568.

others are stated by Payen,* relating to two horses, which lost less fat in their excrements, than was found in their food. The two horses together weighed 1880 pounds. During 14 days on which they were fed solely with hay, they consumed 664 pounds, in which were contained 13.28 pounds of fat. During that time they gave 452 pounds of excrements, which contained 7.344 pounds of matter, soluble in ether; that is, 5.936 less than was contained in the food. During this experiment, the one horse had lost 26 pounds, the other 50 pounds of its weight. This experiment was intended to prove, that fat is also consumed in the body, and that it need not always be produced from other substances.†

The opinion that fats may really be produced in the animal body from the food, is strongly supported by the fact, that some fats are actually and necessarily produced; for instance, the fats of the brain, cholesterine, cetine, the fats of the genus capra, &c. Now, if fats are produced in the animal body, it must be either from other fats, or from other substances, such as starch. Both processes are the same, in so far as, in every case, there must be a re-arrangement of the elements. In a scientific point of view, therefore, there is nothing unlikely in the opinion that animals are able to produce fats; and Dumas, therefore, was probably in error when he stated, that plants prepare fats for animals, and that animals *cannot* do this of themselves.

Of the purposes served by the fats in the animal body, we shall afterwards speak.

6° When we examine with the microscope such seeds as

* This example from the cow, quoted by Liebig, is rejected by Dumas, because there is so much difference between the quantity of food, butter, and excrements. Comptes Rendus, 6 Mars, 1843, p. 559.

† Various other experiments have since been published—the best conducted and most trustworthy of them by Boussingault,—all of which concur in showing the importance of the vegetable fats in maintaining the condition of the animal body. In this as in many other vexed questions, the truth appears to lie in the middle between the extreme opinions of Liebig and Dumas. The fat of the food is the usual and natural source of the fat of the animal. But if the food be deficient in fat, the animal appears in certain circumstances to have the power of forming it from starch, sugar, and other substances.—*J.*

yield oil by pressure,—for instance, the almond,—we perceive little drops, lying close together against the interior walls of the cells. It is these drops which are separated by pressing the seeds at the common temperature, and thus the oil is obtained. It is known, however, that from such seeds a much greater proportion of oil can be expressed, after they have previously been heated to a certain temperature. By this heating a farther portion of oil, contained in the seeds, but in a state of combination, is liberated, and may now also be expelled by pressure. This heating is performed either by roasting, or by exposure to steam or hot water. It is sufficient to elevate the temperature to the degree at which albumen commonly coagulates, namely, about 144° Fahr.

The fatty seeds contain in their cells, besides these oily drops, a large quantity of irregular globules, consisting of a yellowish semi-transparent substance. This is a compound of albumen and gluten with oil, probably a chemical combination, from which part of the oil is liberated when the albumen is heated, and thus transformed from one isomeric condition into another;—(we cannot say here *coagulated*, since the albumen is in a solid state already;)—this being a modification, which albumen, both in plants and animals, very readily undergoes. All the oil, however, is not liberated by this process, nor in all fatty seeds in equal proportion, some of them requiring a much higher temperature, or repeated pressure and heating, to give off all their oil. Lintseed, for instance, parts with its oil much less readily than almonds. Hence the reason why all these oils contain albumen, and, for some purposes, must previously be purified from this substance (patent oil).

All these seeds,—the castor oil bean, hemp-seed, &c.,—contain starch before they have reached maturity. But this starch disappears as the quantity of fat oil increases. As soon as the latter has attained its maximum, that is, as soon as the seed is completely developed, not a trace of starch is to be found. Thus, it is highly probable, that the starch serves to form the fatty substances; that the fats are formed from starch in the cells themselves, while the albumen and gluten, supplied from

the saps, are only deposited in them. The simple composition of some seeds may, ere long, explain the formation of fats, and throw light upon the chemical conversion of starch into fats.

In every case where fats are produced from any substance, there must also be produced at the same time either highly oxidised compounds, or else oxygen itself must be liberated. But substances containing so large a proportion of oxygen, as should be produced during the change of starch into fat, are not known to exist in plants. We are not acquainted with any simple constituent of plants, which, after being produced from other vegetable substances, can take up the oxygen left behind after the fat has been produced. In this formation of fat, we may thus easily and unhesitatingly recognise one of the many sources of the oxygen given off by plants.

The oxygen from the starch may be diffused through many other parts of the plant, to its leaves, where it can pass out through the cell-walls or air-vessels, to be in this way discharged into the atmosphere.

If, then, such a change does really happen in seeds, it may take place as follows:—

	C	H	O
To 7 equiv. of starch, ...	84	70	70
Add 8 equiv. of water, ...		8	8
And we have	84	78	78
Which are equal to—			
1 equiv. of margaric acid, ...	34	34	3
1 equiv. of elaic acid, ...	44	40	4
2 equiv. of oxide of lipyle, ...	6	4	2
Oxygen, ...			69
Making as before, ...	84	78	78

This formula, however, should not be considered as correct until it has been ascertained, that in these seeds all the fat is produced from the starch, and that no other substances are formed at the same time from the elements of starch. From the simple composition of some oily seeds, which consist of

cellulose, protein compounds, and fats, the latter does not appear to be likely.

The supposition, however, that wherever we find fats in plants, they must have been formed from starch, would be a hazardous one. In some seeds which are unripe, we find, at an early period, globules of a fat oil, mixed with granules of starch. The surface of the granules of the pollen of flowers is covered with fat in combination with wax; and in most other parts of plants some fat may be found. We cannot state with certainty, that this fat has always been produced from starch. There is no doubt that to be so converted, the starch must exist under peculiar circumstances; for it is by no means true, that plants, which contain much starch, contain also much oil. But wherever fat has been formed from starch, under any favourable influence,—for instance, that of protein compounds,—it has so great a tendency to diffuse itself, or to become divided by capillary attraction,—that it is readily carried to other parts of the plant, and must penetrate wherever there is not water enough to keep the cell-walls in a moist state, or where albumen is not present in sufficient quantity to retain it. Hence the reason, why it is found on the exterior of the pollen, and why it exists in the perisperms of oily fruits, when these have begun to dry. But if the fat be diffused through an aqueous fluid, or combined in it with albumen, its globules are then too large to be carried through the cell-walls. In this case, the fats remain confined where they have been separated, as we see in the cocoa-nut.

It is an incontestable fact, that during the germination of seeds their starch is converted into dextrin and sugar by the diastase produced, and that these are supplied as food to the young plant. The ripe, oily seeds contain no starch. In these the function of starch and albumen in germination is probably performed by the fat oils along with the albumen; so that, during this process, the fats undergo a decomposition and are changed into food for the young plant. It is not known, however, what the nature of this decomposition is.

Lehmann has recently shown* that a mixture of albumen

* Franz Simon, Beiträge zur Phys. und Path-Chemie, Bd I. S. 73.

and fat possesses the power of acting chemically on other substances; for instance, of converting milk-sugar into lactic acid. These two substances, when mixed, therefore, may perform in plants entire series of transformations, since they have a tendency to change sugar into acids, as necessarily results from Lehmann's experiments. During this change the coagulated albumen is also brought into a soluble state; so that the fat, which by the influence of albumen can change sugar into lactic acid, may be able to react on the albumen, and to render it soluble. By such a reciprocal action of fat, albumen, and sugar, the coagulated albumen in certain parts of living plants may be removed and carried to other parts; neutral fats, in that case, according to Lehmann, not being always changed into the analogous fatty acids, but into others also—as for instance, elaïne into butyric acid. This is, indeed, an important discovery for Zoochemistry.* (See *Milk*.)

I. Chlorophyle.

It has been ascertained, by incontestable proofs, that from the green parts of plants, when subjected to the sun's rays, oxygen is given off. This important fact, however, still stands alone in science. It has not hitherto been brought into connection with that frequent change of materials, which takes place in plants, and of which it is merely the final result. It is clear, that this oxygen must originate in one or more substances, existing either in the places where the oxygen is separated, or in some other part of the plant; and that its being given off from the green parts must be the consequence of the formation of substances poor in oxygen, from others rich in this element; since it is by such a change of substances only that oxygen can be disengaged from plants.

* The researches of Pelouze and Gelis, of Bernard and Barreswil, and, more recently, of von Blücher, on the production of lactic acid and mannite, by the action of fresh curd upon solutions of cane, grape, starch, and milk sugars, at a temperature of 85° in the presence of finely divided carbonate of lime (chalk), are no less interesting in a physiological point of view, than those of Lehmann, referred to in the text. The method described by von Blücher (Pogg. Annalen, lxiii. p. 427) for forming this acid and its compounds on the large scale from cane sugar, is so simple as to leave scarcely anything to be desired.—*J.*

Now plants do contain substances poor in oxygen. We shall enumerate them when treating of the excretion of oxygen by plants; and we shall then show, that this excretion merely results from the formation of these substances poor in oxygen. We have already alluded cursorily to this subject in describing the fats (p. 257).

1° There is one substance almost universally diffused through plants, which deserves to be noticed in this place. This is the so-called chlorophyle. The leaves are coloured green by it, and since the green parts give off oxygen, it occupies the very place where this excretion is performed.

It is a striking fact, that young leaves have a much lighter green colour than those which are older, showing that the quantity of chlorophyle increases with the age of the leaves. If chlorophyle were a substance poor in oxygen, and were derived from substances rich in oxygen, this fact alone would be sufficient to explain the power, which the green parts possess, of separating oxygen. This, however, is not the case; chlorophyle is rich in oxygen. Nevertheless, the leaves give off oxygen, not *because* they *are* green, but *whilst* they *are becoming* green.

For the purpose of illustrating this statement, I shall briefly glance at the history of chlorophyle.

Some years ago I made investigations in regard to this subject,* and showed that the substance, described by Pelletier and Caventou, under the name of *chlorophyle*; by De Candolle, under that of *viridine*; by Macaire Prinsep, under that of *chromule*; as also by Clamort Marquart, and others,—is nothing but a mixture of wax and pure green colouring matter.

It is of importance to make this observation at the outset, because the production of both these substances—of the wax, which is a kind of fat, and of the green colouring matter, which is mixed with it—is connected with the same function of plants, namely, the excretion of oxygen. Thus, there is a genetic connexion between the production of wax and that

* Natuur-en Scheikundig. Archief D. II. p. 1, en Natuurk. Bydragen. Deel VII & 1. p. 82.

of the green colouring matter in the leaves. In this respect, these two substances ought to be viewed and treated of together, although they must not be confounded in a chemical sense.

When green leaves are digested with ether, the liquid becomes green. If we then evaporate the solution, and digest the residue with alcohol, a large quantity of a white fatty substance is deposited after cooling, the green colouring matter being held in solution.

2° It is proper, before we proceed to state how far we are acquainted with the pure green colouring matter, to make some general remarks as to this mixture of wax and colouring matter. In a botanical sense, this *mixture* has the name of chlorophyle; in a chemical sense, it is the pure green colouring matter only, which should bear that name. To prevent confusion, I shall represent the former by B (botanical), the latter by C (chemical).

We find similar mixtures of a waxy fat, with colouring matters, in other exterior parts of plants besides the leaves. It abounds in the skin of fruits, especially of such as are coloured. This skin first assumes the general colour of the plant, namely, green; it then turns gradually red, &c., and at the same time increases continually in hardness, and often also in brightness.

If such skins of fruits (for instance, those of common apples) are digested with ether, a large quantity of a waxy substance is dissolved;—this wax varying in colour according to the colour of the skin, being grey when obtained from apples, and of a beautiful orange colour when obtained from the berries of the mountain ash.

The wax of these coloured fruit-skins has, no doubt, the same origin, though not the same composition, as that of green leaves and unripe fruits. But the green colouring matter of the unripe fruits has been replaced by another,—that of the ripe fruits; the former being probably changed into the latter.

An observation of Senebier* is here worthy of peculiar attention. He found that red and yellow parts of plants give off no oxygen, when subjected to the light of the sun, this

* Physiologie Végétale, tome 5. p. 71.

being done by the green parts only. We are apparently entitled to draw from this the conclusions—the first of which we shall presently see to be erroneous—that the green colouring matter originates in substances which give off oxygen, being itself poor in oxygen; that such parts of plants as have another colour than green, cannot be produced in this way; and finally, that such colouring matters as are left behind after the green matter, whether of the fruit-skin or of the leaves, has disappeared, either were partly present before, mixed with the green colouring matter, or have been produced from it by decomposition.

The coloured wax, extracted from the skin of the berries of the mountain ash by ether and alcohol, gives off its colouring matter to sulphuric and hydrochloric acids, to potash, and to soda; and becomes almost white. It has properties similar to those of cerine; and though this apparent conformity has not been confirmed by elementary analysis, yet it appears that we are entitled to consider it as a substance belonging to the wax family. When treating of the fats (p. 256), we mentioned three different kinds of wax, viz., cerine, myricine, and cerosine. Others, besides, exist, which will be noticed in the account of the principal parts of plants, such as roots, barks, &c. The class of waxy substances is probably as large as that of the resinous, and is, alas! but little known as yet. The same waxy substance is obtained from mountain ash berries, and from the bark of apple-tree roots, during the preparation of phloridzine. Its composition is represented by—

$$C^{40}\,H^{32}\,O^{10} = 20(C^{2}\,H^{1\frac{1}{2}}) + O^{8} + 2\,H\,O^{*}$$

The properties of these two varieties of wax are nearly identical.

* Scheik. Onderz. Deel II. p. 157.

	No. I. from the bark of the apple-tree.		No. II. from mountain ash-tree berries.	
C	69.17	69.16	68.89	69.64
H	8.91	8.85	9.22	9.32
O	21.92	21.99	21.99	21.04
		Atoms.	Calculated.	
	C	40	68.67	
	H	32	8.94	
	O	10	22.39	

The same is the case also with those, which are obtained from the skins of apples, grapes, calabashes (Cucurbita lagenaria), Spanish pepper, cucumbers, oranges, and citrons. The waxes from all these fruits, like the fruits themselves, differ in colour, and all are affected by re-agents, just as the B chlorophyle is. If obtained by means of ether, the proportion of fat is considerably larger; if by means of alcohol, there is more colouring matter, the latter being more soluble in alcohol, as the fatty substance is in ether.

As to the origin of the wax in the skin of fruits,* it dates from the time when the fruits were green. The wax being at that time formed in them, is left behind after the green colouring matter of unripe fruits has been changed during ripening. If we add to this, that in the leaves which have changed their colour in autumn, a fatty substance is abundantly found, similar to that which exists in the skins of fruits and in the green leaves;—that leaves, which become red in autumn, belong to plants having red fruits;—and that such plants as have yellow leaves in autumn bear mostly fruits of a yellowish colour,—we cannot doubt any longer, that the red and yellow colouring matter in the skin of fruits is produced from the pure C chlorophyle.

3° The degree in which the action of light contributes to the change of colour in the C chlorophyle which exists in the perisperms, and to the production from it of the colouring matter of the skin of ripe fruits, is clearly to be inferred from the general green colour of such fruits as are not sufficiently exposed to the light of the sun, while another colouring matter exists on the sunny side; and from the other fact, that leaves, when deprived of the action of light, become colourless, while if completely exposed to its action, they secrete an abundant portion of B chlorophyle. This important difference in the action of light upon the skins

* We call it *wax* because it has similar properties with wax. The composition is different from that of common wax. That which exists in the skins of fruits, seems to be a substance in a state of transition to cerine and myricine. At page 256 we have mentioned some kinds of wax, but it seems that there are others still. Solly, for instance, (London and Edin. Phil. Mag. 1837, II. p. 452) found in the sap of the galactodendron, a peculiar waxy substance, which he calls *galactine*.

of fruits and leaves, is attributable to the same cause as the change of colour in the leaves during autumn,—namely, that light can only produce B chlorophyle when there is sufficient material at hand, whence it can be produced anew from new substances, as often as the existing quantity is decomposed by the same influence of light; and that, as soon as this stock is consumed, the green colouring matter is itself decomposed, and other compounds, not coloured green, are formed from it.

Light exerts a powerful action in keeping the parts of plants green, and also a powerful decomposing action upon all colouring matters, the C chlorophyle included. Asparagus, potatoes, young growing leaves, &c., become green whenever they are exposed to light. Thus, there must be a substance generally diffused through plants that causes the production of chlorophyle,—a substance present, even where no green colour is perceived, and in parts not exposed to light,—since, whatever part of a plant we expose to the light, it will become green, provided it be a part which ought naturally to be deprived of light. This happens not only on the surface, but also beneath it, as far as light can penetrate through the semi-transparent parts. Hence the reason why, in almost every part of herbaceous plants, B chlorophyle is found, though chiefly in their leaves, which are usually broad expansions, admitting of the action of light upon their extended surfaces.

Many plants have leaves either speckled or spotted, or of a colour entirely different from green; others are not coloured at all. From this, we are induced to conclude, that in such plants or parts of plants as are not green, the materials are wanting from which the chlorophyle is produced. We may occasionally remark, in summer, one single spot of an entirely green leaf coloured red by the pricking of insects; the same effect is caused by hail-storms, and is thus a consequence of the leaf's being locally wounded. The green colouring matter, present at the place, is decomposed by the light, no new portion is formed, and generally this part of the leaf acquires the same colour, which would have been assumed by the whole leaf in autumn. From this, therefore,

we learn that the change of colour in the leaves during autumn is a chemical alteration of the green colouring matter by light without the intervention of any function of the plant.

The colour of leaves which are not green, is either such as universally exists in the saps, or is caused by some peculiar substance being locally produced, of which no other part of the plant possesses even a trace. Thus in many plants we find the under surface of the leaves of some other colour than green, or covered with spots. These colours deserve our attention in passing. The yellow colour is frequently met with in variegated, striped, and spotted leaves. In this respect, the Ilex aquifolium is remarkable:—at one time, it has green leaves with yellow borders; at another, yellow leaves with green borders. The Aucuba japonica has alternately green and yellow spots. The Celtis australis has green leaves with yellow stripes on the nerves of the leaf. The same is the case with the Carduus marianus. Such spots, if they have been formerly green, are in the condition of the yellow leaves in autumn; or, if they have never been green, there must have been from the commencement of their growth a want of the material, through which they could have become green. The latter is clearly seen in the Arum pictum. For this reason, many of these leaves which either have yellow stripes, or are otherwise coloured yellow, become entirely green by better cultivation.

An interchange, similar to that which we perceive between yellow and green, is found also between red and green. In this case, however, two different colouring matters must of necessity exist. The Rubus rosæfolius has green leaves, with fine red borders; the leaves of the Maranta zebrina are purple below, and green, with yellow stripes, above. In this respect, the Maranta bicolor is especially remarkable.

These diversities, the cause of which is always connected with that of the change of colour in autumn, ought to be thus explained. The green colouring matter, which originally exists everywhere, is decomposed by light in the changed spots, and gives rise to a red colour, the green not being restored. This is also the case in Fagus sylvatica pur-

purea, in which, together with the chlorophyle, a red colouring matter exists, produced by light, the green diminishing in quantity the longer the leaves are subjected to the action of light. The white lily, when young, is of green colour.

The sea-green colour, *color glaucus*, arises from a thin layer of wax, spread externally over the green leaves. The leaves of Echium fastuosum and Sedum dasyphyllum, when kept for some moments in ether or alcohol, become green, and lose the thin layer of wax with which their surface was covered. For the same reason, grasses, when covered with dew, become sea-green. The small drops of water of which dew consists, and which are not distinguished by the eye, make the chlorophyle appear with the *color glaucus*. In some plants this quantity of wax on the leaves is considerable—such is the case with the Ceroxylon. Grapes, plums, and other fruits, especially that of the Myrica cerifera, contain a large portion of this excreted wax ;* and I found it in the largest quantity upon the exterior surface of the bracteæ of Musa paradisiaca. The surface of the leaves of many species of Encephalartos is covered with a thick layer of wax. (Miquel.)

4° After having thus enumerated some facts, from which we chiefly learn, that wax, along with a green colouring matter, exists in leaves and unripe fruits,—wax with a red colouring matter in the red leaves which appear in autumn and in the red fruits,—and wax with a yellow colouring matter in the yellow leaves in autumn, and in the yellow fruits,—we shall mention some experiments of Berzelius,† made for the purpose of ascertaining the properties of the pure green colouring matter of the leaves.

Berzelius made his experiments with leaves of Sorbus aria. I have repeated them with leaves of vines, syringa and poplars, and with grass; and I obtained exactly the same results.

If fresh leaves are digested with ether, the colour of the liquid is darker than that obtained from dried leaves,—the latter being more or less yellowish, though, in other respects,

* To this coating of wax is owing what is technically called *the bloom*, so much admired upon our grapes and other fruits.—*J.*

† Annalen der Pharmacie, Bd. 27, S. 296

similar to that from fresh leaves, but yielding a smaller quantity of pure chlorophyle.

When the solution in ether is evaporated to a very small bulk, a substance is deposited, which must be digested with alcohol till the latter becomes yellowish. The residuum is added to the ether, which had been left behind; the alcoholic solution is evaporated. If what remains from this solution is again treated with warm alcohol and the solution allowed to cool, a large quantity of wax is separated on filtration. We shall give its composition below. If the green alcoholic solution is evaporated to dryness, a substance is left behind, which is almost entirely soluble in hydrochloric acid, from which it is precipitated again by water; the water with which it is washed acquires a yellow colour. After the chlorophyle is thus purified, it is with difficulty soluble in alcohol and ether; it imparts to these liquids a blackish green colour, and renders them opaque. If a strong solution of potash is poured upon it, the solution assumes a fine grass-green colour, and a black substance is left behind undissolved. If the potash solution be super-saturated with acetic acid, the chlorophyle is again precipitated. It is now pure green, does not melt at 392° Fahr., and is almost entirely soluble in hydrochloric acid and potash, giving a fine grass-green coloured solution.

Pure C chlorophyle, extracted by strong hydrochloric acid from what was contained in the alcoholic solution, and was left behind after evaporation, may be separated from the acid solution by means of marble. It is insoluble in water, but soluble in alcohol and ether—the solutions having a green colour, which is, more or less, blueish, if the substance was previously dried. It seems to be somewhat changed by drying. It is soluble in strong sulphuric acid, giving a fine green solution, from which it is again precipitated by water. Hydrochloric acid has the same reaction upon it, but in this case a pale yellow substance is, more distinctly than in the former, left behind. Berzelius calls this substance, xanthophyle, and it is the cause of the yellow colour which the leaves assume in autumn. This yellow substance of the autumnal

leaves does not exist in the C chlorophyle of the summer leaves; but it becomes perceptible when the green colour is decomposed into two products, the one blue, the other yellow. If chlorine is passed through a solution of pure chlorophyle in hydrochloric acid, the liquid becomes colourless and leaves a white flocculent matter behind, part of which is soluble in ether. Both portions, that which is soluble, and that which is insoluble (in ether), are of a fatty nature. Thus it seems, that chlorophyle, free from wax—that is, the pure colouring matter—is changed by chlorine into wax, and another fatty substance. This change may be effected either by oxidation, or by separation of hydrogen. At all events we learn from this action of chlorine, that the wax in leaves may be partly produced from pure C chlorophyle. The latter is soluble in acetic acid. By nitric acid it is rendered yellow, without any separation of gaseous products. It is soluble in potash and ammonia;—the solutions having a beautiful green colour. Carbonate of potash, and carbonate of ammonia, and lime and baryta waters, have the same power. The alcoholic solution of chlorophyle is precipitated by acetate of lead.

C chlorophyle from dried leaves, is different from the former in many respects. It is similar to that part of the colouring matter from fresh leaves which is held in solution by ether, and which is the least soluble in alcohol. If we bear in mind, that when green chlorophyle is prepared in the air, part of it becomes yellow, and that, according to the experiments of Berzelius, leaves, dried in the air, contain less green and more yellow colouring matter, we should think it a sound conclusion, that the green colouring matter becomes yellow by absorption of oxygen. But just the opposite is the case; chlorophyle becomes yellow by the action of de-oxidizing substances. Thus it appears as if, both when the leaves are dried, and when the pure chlorophyle is prepared in the air, part of the latter were wholly decomposed and new products formed. As, however, the yellow substance, separated by chlorine from a solution of pure chlorophyle in hydrochloric acid, has the properties of fat,—part of the wax, which we find

mixed with pure chlorophyle, must be a product resulting from the decomposition of pure chlorophyle, and similar to that product which is formed by the de-oxidation of part of the constituents of chlorophyle. If with this we connect the change of the colour of the leaves into yellow during autumn, and the considerable portion of wax they then contain, it is clear that this is owing to a chemical change of the chlorophyle. It is of importance, therefore, to investigate this yellow matter, which is also accurately described by Berzelius.

That part of the C chlorophyle, which was held in solution by ether, and left behind by alcohol as a yellow substance,—and of which dried leaves contained a very large amount, — was dissolved in ether, and hydrochloric acid added to the solution. Two layers were formed; the ethereal was yellow, the acid green. In the latter, much blackish green fat floated, which was separated, and washed with hydrochloric acid. After being saturated by suspending in it a piece of marble, the acid solution deposited chlorophyle, which was again washed and boiled with hydrochloric acid; the greater part was now dissolved, but a black residue was left behind. Marble was again added to the acid, when the chlorophylè was separated, having a yellowish-green colour, and the grass-green liquid became blue. This peculiarity we noticed above, and it is a very remarkable one, since, as every one knows, by mixing blue and yellow, green is produced; since, in many fruits, originally green, a blue coloured matter is to be seen; and since the yellow colouring matter, found here to such an extent in the leaves, after being dried in the air, can scarcely be produced in any other way than by the drying,—that is, by a chemical change of the chlorophyle while drying. Thus we find, among the products of decomposition of pure C chlorophyle, a blue and a yellow substance.

This mixture of yellow and blue colouring matters, in the dried leaves, has almost the same properties as chlorophyle from fresh leaves, with this exception only, that when precipitated from the solution in hydrochloric acid, its appearance is different from that which is yielded by fresh leaves.

The black substance we have just spoken of, quickly attracts moisture from the air. It is dissolved by sulphuric acid; the colour of the solution is a mixture of brown, yellow, and green. The colour of its solution in the other fluids, in which pure chlorophyle is soluble, is nearly the same. It is a third product of decomposition from pure chlorophyle.

From these experiments of Berzelius, of which I have expressly given a fuller account, because of the nature of the diversity of colour in the leaves—this diversity being easily traceable to a few colouring matters only, and produced by different influences—we may conclude, first, that the green colouring matter of the leaves is readily decomposed into three different substances, one yellow, another blue, and a third black; that according to the proportion of these three, mixed with the green one, a different kind of green must be produced: therefore the leaves must be of a different green colour, not only because of a different proportion of chlorophyle, but also of a different mutual proportion of these three colouring matters. It is well known to painters, that every variety of green may be prepared from blue, yellow, and black.—so that even when the C chlorophyle is decomposed into these three substances, it may yet impart a green colour to the leaves.

The quantity of pure C chlorophyle, contained in the leaves, is exceedingly small. Berzelius says, it is not more than dyed cotton contains of colouring matter.

If a tincture of pure chlorophyle is exposed to sunlight, the green colour becomes yellow within a few hours. When a solution of pure chlorophyle in ether and hydrochloric acid was kept for five months in a bottle, half filled up, the green was entirely changed into yellow. (Berzelius.) These experiments are of importance. We learn by them, first, that the green colouring matter is decomposed, a yellow one being left, and the blue and the black destroyed, both with and without the influence of light. Secondly, that probably a similar decomposition and reproduction of the green colouring matter in green leaves is constantly going on under the influence of light. This continual decomposition of the green colouring matter may partly

It would, however, be wrong to suppose that not only the formation of substances, poor in oxygen, such as wax, which are mixed with C chlorophyle, but also the formation of the green colouring matter itself, must be attended by a separation of oxygen, when the general vegetable substances, such as starch, are used for that purpose. (See page 263.) On the contrary, experiments by Berzelius show that the colouring matter, as it becomes green, absorbs oxygen, and that it either loses oxygen or takes up hydrogen when it becomes colourless.

As regards this property of being oxidized and de-oxidized, chlorophyle may be compared with indigo. With a view to such a comparison, Berzelius exposed a solution of pure green chlorophyle in hydrochloric acid to the action of hydrogen in the nascent state. He laid a piece of zinc in the solution and excluded the air from the vessel containing it. On the disengagement of the hydrogen, the green colour became completely yellow. When the yellow liquid was evaporated in an open vessel, it gradually became green again, though in a less degree than before. When heated, the green colour was not restored, but the yellow substance became red; it contained a mixture of a yellow and a red matter. This production of a red substance from chlorophyle is of importance, because in autumn many leaves become red instead of yellow. We do not know yet, however, any relation between this red matter left behind from the solution in hydrochloric acid, and the red colouring matter of the autumnal leaves. The latter is probably formed from the green by the absorption of oxygen under the influence of an alkali, while at the same time a smaller quantity of wax is produced, but this is not yet by any means proved.*

Berzelius has also made some experiments upon this red colouring matter of the autumnal leaves.† He remarks that, while a great many leaves become yellow in autumn, such, on the contrary, as belong to plants with red fruits, become red.

* When repeating all these experiments of Berzelius, I obtained precisely the same results.

† Annalen der Pharmacie, Bd. 21, S. 262.

He therefore thinks, that an intimate relation exists between the red colour in fruits and the red colour in such leaves. He found that the colouring matter which he prepared from cherries and currants, was similar to that which he obtained from red autumnal leaves of cherry-trees and currant-shrubs. He also found that both fruits contain the same colouring matter. It is soluble in any quantity of water or alcohol, but is insoluble in ether. Its solution in water cannot be evaporated by heat, without becoming brown and less soluble. The solution has a beautiful red colour; but when mixed with milk of lime, a greyish green precipitate is produced. From this Berzelius draws the conclusion, that it is not a combination of a blue colouring matter with an acid, as had been supposed. But when the colouring substance in its impure state (as it is obtained, when the fruit skins are treated with water, that is, mixed with malic and citric acid) is mixed with acetate of lead, a bright blue precipitate is produced. Now, since ammonia renders the red colour brown, it would appear that the experiment with lime indicates rather a decomposition by means of the alkali. The red colouring matter from ash-tree berries gave a green precipitate with acetate of lead, which therefore again points at a mixture of yellow and blue.

In the red autumnal leaves of cherries and currants, Berzelius found wax and fat, besides the same red colouring matter. These were precipitated by adding water to the alcoholic tincture, in which they were dissolved, the red colouring matter remaining in solution. When this solution in water was mixed with acetate of lead, a green precipitate was formed, which after a few moments became greyish brown. The colouring matter obtained by precipitating the lead with sulphuretted hydrogen, and evaporating the liquid in vacuo, had very nearly the same properties as at first.

From the fresh yellow autumnal leaves of pear trees, Berzelius obtained by alcohol a yellow substance mixed with fat; of which a part only could be changed into soap by an alkali (wax). The yellow colouring matter itself, Berzelius could not wholly separate from this fat. It was insoluble in

water, soluble in alcohol and ether. It was entirely bleached in the air. From its alkaline solutions it could be precipitated by acids. Berzelius thinks it is an intermediate substance between oil and resin; he calls it xanthophyle.

5° It is sufficiently clear from what has been said, that C chlorophyle is a peculiar substance, wholly different either from wax or fats; that it can be decomposed into a yellow, a black, and a blue colouring matter, and that, mixed with these, it really must exist in many leaves; that this mixture must cause a diversity in the green colour of the leaves; that the colouring matter may be decomposed, both by oxidizing and de-oxidizing substances, so as to become colourless at last; and that wax seems to be producible from it, by de-oxidizing actions, though the greater part of the wax in the leaves is derived from another source.

With regard to pure C chlorophyle, we have been able to subject only one single species—that from poplar leaves (*populus tremula*)—to analysis, and that in very small quantities only; *so that we are far from being certain as to its composition.* This analysis has given,

$$C^{18}\,H^{9}\,N\,O^{8}.*$$

Should this composition be hereafter confirmed—for which many analyses of chlorophyle from different leaves would be requisite—then chlorophyle is analogous to the indigo-like substances. Chlorophyle, rendered colourless by hydrogen, will then probably be a hydruret of the green colouring matter, as the white indigo is a hydruret of the blue indigo. The following formulæ exhibit this relation of the two indigos:—

$C^{16}\,H^{5}\,N\,O^{2}$, blue indigo.
$C^{16}\,H^{6}\,N\,O^{2}$, white indigo.

* Scheikund. Onderz., Deel II.

	Found.	Atoms.	Calculated.
C	55.51	18	55.81
H	4.62	9	4.56
N	6.68	1	7.19
O	32.99	8	32.54

This composition suggests the reason, why green chlorophyle becomes white by the de-oxidizing influences which act upon it in the interior of plants, and by which hydrogen is liberated.

As green C chlorophyle contains much oxygen, it does not give off oxygen during its production. On the contrary, it requires oxygen to become green instead of colourless, as it is originally—for it is probably present as white chlorophyle throughout the whole plant, and is rendered green by exposure to oxygen. On the contrary, in chlorosis—when green leaves through sickness become white—the green chlorophyle loses oxygen, or takes up hydrogen, and does not disappear, the action being analogous to that which occurs, when blue indigo is rendered white by sulphate of protoxide of iron.

We can, of course, state nothing as to the constitution of chlorophyle, so long as its composition is uncertain. The same is also the case with regard to its change into the yellow, blue, and black substances mentioned above.

6° The decoloration of the leaves in autumn is an exceedingly remarkable phenomenon. When the vital action of the plant diminishes, most leaves become yellow, some red, others brown. The latter decoloration is especially perceived in leaves, which are not very green, and which abound in juices. It is a formation of humus, a decomposition of the cellular substance into ulmic acid, by means of which all the other metamorphoses of the colouring matters in the leaves are rendered invisible.

We must, therefore, confine our attention to the yellow and red decoloration of the leaves in autumn. Robinet and Guibourt* had already remarked, that such plants as have either red or blue fruits, have red leaves in autumn. The leaves of vines which produce blue grapes, have red leaves in autumn, while such as produce white grapes have generally yellow leaves. This is an important observation, and may be confirmed by many illustrations. It leads directly to the conclusion, that the yellow decoloration of leaves must be owing to a different cause from the red.

* Journal de Chimie Méd., 1827. Avril, p. 161.

The place from which in autumn decoloration proceeds, is different in different leaves. Some begin to change colour at their extremities, others at their edges, others again in the neighbourhood of the nerves, while on others coloured spots appear. Thus, for example, the leaves of Plantago lanceolata change first at the extremity; those of Lythrum salicaria, at the edges; those of Fuchsia multiflora, at the nerves; while those of Ribes nigrum become spotted. These observations indicate an entirely passive decoloration of the green substance. This decoloration begins at the very moment when green colouring matter is no longer secreted or prepared; that is, when the change of materials within the leaf begins to cease.

It is well known, that the period of the year at which this decoloration commences, is very variable. When the temperature is considerably diminished, or when a long drought weakens the plant, the leaves are sooner decolored. We may see a difference even in leaves of the same plant. The Cratægus indica exhibits some red leaves, when by far the greater part are still green. The Olea Europæa has some yellow leaves. All this indicates a difference in the decoloration of leaves, dependent upon the function of each particle, or, perhaps, upon that of the whole leaf.

We are not able to change the yellow colouring matter of autumnal leaves into green by de-oxidizing substances. It consists of wax mixed with a yellow matter. It is left behind, after pure C chlorophyle has been decomposed by light, the blue and black (see page 275) being changed into colourless substances. It is otherwise with the red colouring matter in red autumnal leaves, which is also mixed with wax. The alcoholic infusions of Azalia pontica, A. procera, Vitis hederacea, all of which have red leaves in autumn become green, when exposed to the action of de-oxidizing substances, such as sulphate of protoxide of iron. The red colouring matter, prepared in the leaves themselves during summer, undergoes the same change. The purple colour of the summer leaves of Fagus sylvatica purpurea is changed

into a fine green, when acted upon by sulphate of protoxide of iron.* Diluted acids and alkalies do not act upon this colour so as to modify it. It is attacked and decomposed by them only when very concentrated.

Many experiments have shown me, most clearly, this accordance between the red colour of the skins of fruits, and that of the autumnal leaves. Both are peculiar substances, independent either of acids or alkalies. The observation made by Macaire Prinsep, that the red colour in autumnal leaves is occasioned by an acid produced in the leaves, is entirely erroneous; and so is his opinion, that the red is preceded by the yellow decoloration. Neither is there any relation whatever between the colour of flowers, and that of the autumnal leaves and fruits, as Robinet and Guibourt supposed, nor between the red and other colouring matters which are generally diffused through plants. As yet, however, we have no certain knowledge of the red decoloration of the leaves in autumn, because the chemical composition of the substances which are then present in the red leaves, is still unascertained. It is certain, however, that the C chlorophyle is then wholly decomposed and converted into new products. It is probable that the yellow decoloration arises from the de-oxidation of the C chlorophyle.

H. Mohl,† however, thinks that there is no relation between the chlorophyle and the red decoloration of leaves in autumn, but that the former is connected with the colour of the fruits. The function of the leaves is altered by cold; and Mohl's opinion is, that as the leaves are reddened by light in the cold, so fruits owe the same colour to warmth. Mohl does not ascribe the production of the red colouring matter in autumnal leaves to a change of the chlorophyle, because in such red leaves he found some chlorophyle-globules unchanged. It cannot, however, be denied, that when autumnal leaves which are completely red are digested with

* I do not mean, however, that real C chlorophyle is produced in this case. When a red alcoholic infusion from currants is mixed with hydrochloric acid, and zinc laid in it, it becomes not green, but colourless.

† Diss. Untersuchungen über die winterliche Färbung der Blatter, 1837.

ether, almost no chlorophyle at all is obtained, and that the infusion is red instead of green. Now, it is well known, that very little chlorophyle is sufficient to colour a large quantity of ether green.

Decaisne* has shown that chlorophyle can be converted into the colouring matter of madder, which is originally yellow, and is rendered red by moist oxygen. It is, therefore, probable, that a great many colouring matters within the plants are derived from C chlorophyle, or at least from the same materials from which C chlorophyle is produced.

Botanical physiologists have formed various ideas of the manner in which B chlorophyle is produced. Many of them have supposed it to be green starch; others to consist of little green vesicles; others again, of colourless vesicles, filled with a green liquid, which, as was thought by some, adhere to the cell-walls,—and by others, float freely in the plant-sap just as the blood-molecules float in the blood.

The most correct observations on this point appear to have been made by Hugo Mohl.† He thinks that the sap in plants is never green, but always either colourless or red. When it seems to be green under the microscope, this is owing to a little chlorophyle reflecting green light. In this sap chlorophyle exists as a green jelly, sometimes in a determinate form, sometimes formless, or granular, and sometimes coating the interior walls of the cells.

The amorphous chlorophyle is found chiefly in the Confervæ. In phanerogamic plants, it is either mixed with the granular in the same cell, or appears adhering to each little grain; or finally, the granular is diffused through a mass of gelatinous chlorophyle. The quantity of the latter is often so minute, that it merely forms a little cloud as it were around the grain, or adheres to it in the shape of small threads. In this state it is chiefly found in the so-called fatty plants When it consists of little grains, these are found loosely adhering to the cell-wall, or floating freely in the juice of the cells. By means of these chlorophyle-granules the mo-

* Recherches Anatomiques et Physiologiques sur la Garance, 1837.

† Annal des Scienc. Natur. Bot., tome ix., p. 150.

ism of the humic in the cells has been observed in Valisneria spiralis, and Sarmiento alsinea. Occasionally, also, some granules of chlorophyle are found united to a third mass in the midst of the cell.

Mohl distinguishes between chlorophyle-granules, and granules lying in the chlorophyle. The latter are globules without envelopes lying either with or without order in the amorphous gelatinous chlorophyle. This is very beautifully exhibited in the Conferva. These granules are white, and consist entirely of starch.

When the parts of plants are treated with alcohol, the real chlorophyle-globules are not dissolved,—they only lose their green exterior layer, by means of which the liquid becomes green. This exterior layer consists of colourless wax, and of C chlorophyle. Several physiologists have observed that the globules themselves are not dissolved. This is an important peculiarity, as it shows very clearly the origin of the green envelope, and indicates an intimate relation between the colourless globules within the amorphous chlorophyle just mentioned, the green envelope of the globules, and the kernel of these globules, which remains behind colourless after they are digested with alcohol;—that is to say, the kernel is also a globule of starch, and the green envelope (which, in a botanical sense, must be called chlorophyle, though it certainly consists of two substances, namely, pure C chlorophyle, and wax) is wrapped around the kernel of starch as a gelatinous layer. Mohl found this to be the case in many plants, and he thinks it a general rule, that granular chlorophyle has always a kernel of starch. One chlorophyle-globule contains sometimes two or even more globules of starch. The size of this kernel is very variable, and is inversely proportional to the green envelope. Sometimes it is entirely wanting, and the whole globule consists of chlorophyle; from which it may be inferred that starch is capable of being transformed into B chlorophyle.

This discovery, which is of great importance as regards the exhalation of oxygen by plants, enables us easily to account for the different size of the chlorophyle-globules formerly no-

ticed. When a single globule of starch is changed from the surface inwards into B chlorophyle, that is, into wax and C chlorophyle, which appears as a gelatinous envelope, the globule retains its round figure. When the green layer of one single grain unites with that of the adjoining, the one globule of chlorophyle has two kernels of starch, which afterwards gradually disappear. Such a globule has an elliptic shape. Four globules together form a tetrahædron, &c. When, finally, a whole group of starch-globules passes into B chlorophyle, the product is Mohl's amorphous chlorophyle, in which, from the extension and union of the gelatinous envelopes, traces of starch-globules may still remain.

Mohl thinks that a layer of chlorophyle is sometimes formed from the starch-like substance of the kernel, and sometimes a globule of starch from one of chlorophyle, according to circumstances, and especially according to the degree of light. In the Confervæ, and especially in Zygnema, he thinks it indisputable, that a globule of chlorophyle is formed first, from which afterwards one of starch is produced, because the kernels of starch are much smaller in the young parts than in the older. It seems to be difficult to reconcile this with the character of these two substances. We may suppose that C chlorophyle is converted either into a fatty substance, or into a resin. It is not likely to be converted into starch. When C chlorophyle disappears,—as happens in such parts of plants as are withdrawn from the influence of light—it must be transformed into something else, which is without colour. This must be the white chlorophyle, mentioned above. In oily seeds (p. 259) fat is produced from starch; but it is not probable, that, conversely, a fatty substance, such as exists within the B chlorophyle, should be converted into starch. Mohl's observations may be, nevertheless, perfectly correct, and I have not the least doubt, that the starch kernels of the chlorophyle-globules are larger in the older parts of Zygnema, than in the younger;—for there is nothing to prevent us from supposing an increase in the size of the starch kernel, though part of the exterior layers of the starch-globules be continually converted into

chlorophyle, provided the latter change be inferior to the increase in the starch-globule.

It is sufficiently known, that the influence of light causes the change of starch into chlorophyle. Every part of amylaceous roots becomes green, on exposure to light. The parts of plants which become green, all without exception, contain starch; and in autumn, when this green colour of the leaves continually decreases, the starch also decreases, and finally disappears so far, that no further trace of it can be detected by iodine. From these observations it follows, that starch, which is so generally diffused through plants, serves to form B chlorophyle, under the influence of light; the latter substance being a complex one, and consisting chiefly of wax.*

All that we have previously said, therefore, (p. 261) in regard to the change of starch into fats, holds good also, to some extent, as to the change of starch into one of the constituents of the botanical chlorophyle. In the leaves or other parts of plants, which contain starch, one of the products is wax, which is a chief part of the mixture that constitutes the green colouring matter. The composition of this wax is (p. 270)—

$$C^{15} H^{15} O.\dagger$$

If no other products be formed at the same time, this wax is produced from starch by the liberation of oxygen;—5 equivalents of starch producing 4 equivalents of wax, and giving off 56 equivalents of oxygen. Thus,

* From an observation published by Raspail in 1833, it appears that the starch in the cotyledons of Acer plantanoïdes is surrounded with a green colouring matter. Hence in some cases chlorophyle may also be formed without the influence of light. Nouveau Système de Chimie Organique, p. 77. The embryo in the seed of the citron has a green colour.

† Wax from grass (I.) and from Seringa-leaves (II.), gave, after analysis (Scheik. Onderz. Deel II. p. 157) —

	I.	II.	Atoms	Calculated.
C	79.83	80.46	15	79.98
H	13.33	13.28	15	13.05
O	6.84	6.26	1	6.97

5 equiv. of starch,=	$C^{60} H^{50} O^{50}$
With 10 of water,=	$H^{10} O^{10}$
Make, ...	$C^{60} H^{60} O^{60}$

And—

4 of wax are equal to ...	$C^{60} H^{60} O^{4}$
Leaving to be given off, ...	O^{56}

A large quantity of green leaves contains but an exceedingly minute portion of green matter. That which is extracted from leaves by ether, consists chiefly of a fatty substance. I analysed four very different kinds,—that from the leaves of the seringa, of the vine, of the poplar, and of grass and in all of them I found the kind of wax mentioned above, having the same properties and composition. It was in all mixed with only an exceedingly small portion of C chlorophyle. Thus a large quantity of oxygen must be set free, when wax is formed from starch, and this may account for the important phenomenon, not that green parts of plants evolve oxygen, but that parts of plants, *while becoming green*, give off oxygen. For it appears that the formation of fats is simultaneous with that of the green colouring matter, with which they are mixed within the plant.

This, I think, may explain, at the same time, the use of starch in the leaves.

Lewy* thought he had converted wax into stearic acid, by the action of lime and potash at an elevated temperature, hydrogen being given off. The composition of these substances is calculated by Gerhard in the following manner:—

Stearic acid, ...	$C^{19} H^{19} O^{2}$
Wax, ...	$C^{19} H^{19} O$

But the above formula does not represent the composition of stearic acid; so that the change requires another explanation.

It is likely, however, that wax, produced from starch, can be changed into fats by oxidizing influences within the plant. It may further be held, that wax does not undergo that change within the animal body, since it cannot be changed

* Erdmann und Marchand's Journal, 1843, N. 17, s. 13.

into soap by a weak alkaline solution, and so cannot be introduced into the blood of animals, but must remain in the intestines. (See page 256.)

We are thus led to infer, that starch becoming converted into wax within the leaves, is a main source of the oxygen given off by plants.

Why only such parts of plants as are becoming green or more green, give off oxygen, is a question which still remains to be explained.

Properly speaking, the green colouring matter in the leaves has nothing to do with the evolution of oxygen. On the contrary, the coulourless C chlorophyle, which seems to be present everywhere, becomes green from the *absorption of oxygen*. Thus a small part of the oxygen, produced from the conversion of starch into wax, is employed for this purpose, and is not mixed with the atmosphere.

But this is just the reason why C chlorophyle is not *formed* by the exhalation of oxygen; it only becomes green instead of white, as it formerly was. This can happen only where oxygen is abundant, and this we have seen to be the case when starch is converted into wax.

We may therefore assume as proved, that white chlorophyle, diffused throughout the whole plant, will become green in proportion as starch is converted into wax; because it is enabled, in such proportion, to take up oxygen—to become oxidized, just like white indigo.

Now, the probable composition of green chlorophyle,—$C^{18} H^9 N O^8$, shows that pure white chlorophyle is not produced from starch. It is necessary that an azotised body should get access to starch; that is to say, at the same moment that starch is changed into wax, an azotised body, in a liquid state, must penetrate into the globule of starch, which, during this transformation into wax, is converted into $C^{18} H^9 N O^8$.

We do not know yet what that substance is, but it is certain that it must be one, which is diffused throughout the plant like starch; hence it is probably protein, which is changed into a most beautiful violet-coloured substance by the influence of hydrochloric acid and oxygen.

Protein.

In both plants and animals a substance is contained, which is produced within the former, and is imparted through their food to the latter. To both, its uses are numberless. It is one of the most complicated substances, is very changeable in composition under various circumstances, and hence is a source of chemical transformations, especially within the animal body, which cannot even be imagined without it. It is unquestionably the most important of all known substances in the organic kingdom. Without it no life appears possible on our planet. Through its means the chief phenomena of life are produced.

It is present in all parts of plants, in roots, stems, leaves, fruits, and in their several saps. It is contained in very unlike parts of the animal body. In plants it assumes three different forms, in which it is either soluble in water, or insoluble in water, or soluble in alcohol. In animals it also exists in various forms, being either soluble or insoluble in water. In the insoluble form its structure is variable. It forms different compounds with sulphur, with phosphorus, or with both,—and hence the differences it presents in appearance and physical properties. This substance has received the name of *protein*, because it is the origin of so many dissimilar bodies, and is itself therefore a primary substance.

This substance may be obtained in the form of greyish white flocks, when boiled albumen is dissolved in a weak solution of caustic alkali, and the liquid is then neutralized by an acid. It is also obtained by washing the dough of wheaten flour with water, to separate the starch from it—dissolving the remainder in a weak alkaline solution, and neutralizing with an acid.

In the animal body, this substance is the chief constituent of the blood, the muscles, and many other parts, and affords frequent opportunities for the production of new compounds. It is found in the saps of all plants without exception, even in the young parts of the roots. Like cellulose, therefore, it belongs to the substances which are directly

prepared from their food. It is uncertain whether or not this substance is formed in any other part of the plant: but as the youngest roots contain protein compounds, together with cellulose, it may be carried from the place of its first formation through the whole plant. The property it possesses of becoming readily soluble in water renders this the more easy. But on the other hand, it can assume the solid form, and being deposited in the cells, fills them up, and forms part of the solid constituents of plants. In this form it is found in many seeds, of which it occasionally constitutes the largest part. It is deposited there, but was probably produced at the extremities of the roots, having been originally dissolved in the sap.

This deposition of solid protein in certain groups of cells, within the plants, may be effected by a simple process. Acids in large quantity render it insoluble, therefore the mere access of an acid is sufficient for this transformation. On the other hand, the insoluble protein may be redissolved by alkalies, and hence, after it has been deposited in the cells in a solid state, it may be removed elsewhere by the accession of an alkaline solution.

There are some vegetable saps which are milk-white, owing to the large quantity of protein compounds they contain. For this reason they all become turbid when heated. With fatty oils and water, they form emulsions. These compounds contain sulphur and phosphorus, united to bases and salts. They are very easily altered in their composition, and therefore belong to the most important substances of the vegetable kingdom,—through which also transformations may be excited and maintained in other compound bodies.

Protein, as we have said, is formed in plants, and these impart it to animals in their food. Whether it can also be formed within the animal body, has not yet been ascertained. A decided opinion, on this point, can only be given after experiments have been made upon the subject. But it is unquestionable that the protein compounds within the plant are imparted to the animals in their food, and as these compounds are the principal component parts of the animal body,

this constituent must be supplied, either wholly or in part, by plants.

No impartial observer can either doubt or deny, that protein pre-exists in plants, and is not produced by the weak alkaline solution used to prepare it. For, first, the protein *compounds* within the plant have precisely the same properties as protein itself, provided we exclude those properties which belong to the substances combined with the protein. Vegetable albumen, for example, which is a compound of protein, sulphur and phosphorus, has all the properties of protein, modified slightly by those which belong to sulphur and phosphorus. If we consider farther, that protein and albumen have the same composition in the hundred parts, abstracting the sulphur and phosphorus which the latter contains, we think there can be no doubt that protein does pre-exist in plants.

The formula of protein, deduced both from its numerous combinations with acids and from direct analysis, is $C^{40}H^{31}N^{5}O^{12}$.*

* In 1838 I determined this formula, from the result of a great many analyses. Protein from fibrin, from ox-blood, and from albumen, gave me (Bulletin, 1838, p. 110)—

			Atoms.	Calculated.
C	55.44	55.30	40	55.29
H	6.95	6.94	31	7.00
N	16.05	16.02	5	16.01
O	21.56	21.74	12	21.70

I also found the composition of protein from wheat to be (Bulletin, 1838, p. 111)—

C	54.99
H	6.87
N	15.66
O	22.48

It thus appeared, that plants prepare all or most of the protein for animals, so that animal albumen, animal fibrin, &c., which differ from protein only in containing a small portion of sulphur and phosphorus, must have their origin in the vegetable kingdom. After many vain attempts to determine the atomic weight of protein, I succeeded at last by means of sulphuric, chlorous, tannic, and other acids. (Bulletin, 1838, p. 119, 1839, p. 16. Scheik. Onderz. Deel I. p. 62.)

Sulpho-proteic acid.	Found.	Atoms.	Calculated.
C	50.94	40	50.70
H	6.93	31	6.41
N	15.08	5	14.68
O	18.74	12	19.90
SO^3	8.34	1	8.31

Plants contain compounds of protein with sulphur and phosphorus; but their composition is not yet known. Formerly they were called *soluble albumen*, *coagulated albumen*, *legumin*, and *glutin*; Liebig, however, has thought fit to name the first three *vegetable albumen*, *vegetable fibrin*, *and vegetable casein*. If this nomenclature be correct, it must be founded on a conformity in composition of these three substances, with three protein compounds in the animal kingdom—albumen, fibrin,

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Sulpho-proteate of silver.

	Found.	Atoms.	Calculated.
C	41.96	40	40.86
H	5.27	31	5.17
N		5	11.84
O		12	16.04
$S O^3$	6.33	1	6.70
Ag O	19.72	1	19.39

The composition of two other sulpho-proteates may be seen in Scheik. Onderz. Deel I. p. 65. They have been analysed by Schröder.

Tannate of protein.

	Found.		Atoms.	Calculated.
C	55.15	54.28	58	54.78
H	5.56	5.75	38	5.86
N	10.63		5	10.94
O	28.66		23	28.42

$= C^{40} H^{31} N^5 O^{12} + C^{18} H^6 O^9 + 2$ Aq.

Chlorite of protein.

	From the albumen of the egg.		From fibrin.
C	48.54	48.80	48.70
H	6.15	6.28	6.06
N	14.08	14.13	
O	19.53	19.62	
$Cl O^3$	11.70	11.17	11.56
	From casein.	Atoms.	Calculated.
C	49.17	40	48.76
H	6.39	31	6.16
N		5	14.11
O		12	19.13
$Cl O^3$	12.27	1	11.84

Hence, I think myself entitled to consider the formula of protein, $C^{40} H^{31} N^5 O^{12}$, as established beyond question, unless these analyses can be proved to be incorrect. I have only to remark, that here, as in all the calculations throughout this work, I have assumed the atomic weight of carbon to be 76.437, and that, if the number assumed for carbon be 75, the number of equivalents of hydrogen will be 30, instead of 31. All my attempts to combine protein with bases, and thence infer its atomic weight, have been in vain. (See Bulletin, 1838, p. 112.)

and casein. This conformity, however, still remains to be proved. The special character of these animal substances is determined by the small portion of sulphur and phosphorus they contain, and by which they differ from each other, and from pure protein. The proportions of sulphur and phosphorus in the three vegetable substances are still unknown; and, therefore, the names proposed by Liebig cannot be applied to them. Moreover, both coagulated vegetable albumen and legumin differ so much from animal fibrin and casein, both in form and appearance, that they ought not to have a similar name. Thus, until the identity of these vegetable and animal substances is sufficiently proved, we must persist in giving the name of *legumin* to that substance which is precipitated in white flocks, when the infusion of crushed peas and beans in warm water is mixed with an acid. (Braconnot.)

By *vegetable albumen*, we mean that substance which, being soluble in water, is precipitated from the saps of plants by heat, by alcohol, and by acids. It is soluble in weak alkaline liquids, from which it is precipitated by acids, and (keeping out of view the sulphur and phosphorus) it has the same composition as protein.

By *coagulated vegetable albumen*, I mean that compound of protein, sulphur, and phosphorus—existing in the seeds of corn, in almonds, &c.—which is insoluble in water.

By *glutin*, I mean the substance which can be extracted by alcohol from Beccaria's gluten.* The formula of glutin from wheat is :—

$$10\,(C^{40}\,H^{31}\,N^{5}\,O^{12}) + S^{2}.$$

* Different grains contain different quantities of these substances. The following is a brief enumeration of the proportions of starch, albumen, and glutin, which they severally contain.

	Starch.	Albumen and glutin.
Winter wheat, ...	77	19
Summer wheat, ...	70	24
Barley, ...	79	6
Rye, ...	61	5
Oats, ...	59	6
Carolina rice, ...	85	3.6
Peas, ...	33	17.6

For a more complete table, the reader is referred to Johnston's *Lectures on Agricultural Chemistry and Geology*, p. 777.

It had been proved, that the chief constituent of the animal body is prepared by plants,—that animal fibrin, albumen, and casein differ from each other only by the small proportions of sulphur and phosphorus which they contain—and that they yield the same protein as vegetable albumen does, when treated with alkalies. Liebig has since discovered a similar identity between vegetable albumen, coagulated vegetable albumen, legumin, and glutin, in so far as their relative proportions of carbon, hydrogen, and nitrogen are concerned. The analyses he has published, have thus more fully confirmed the conclusion that all these substances are protein-compounds.* Much, however, remains to be explained, before we can be said to have a thorough knowledge of these four vegetable compounds.

It is certain, however, that they contain protein-com-

* It followed from the experiments, mentioned above (p. 293), that coagulated vegetable albumen contains protein. More recently (Annalen der Chemie und Pharmacie, 1841, Bd. 39, S. 129, and Bd. 40, S. 65) Liebig has published some analyses, made by Jones, of the albuminous constituents of plants, not separated from the small portions of sulphur and phosphorus, with which they are mixed. These are as follows:—

Coagulated vegetable albumen, ...	C	53.83
	H	7.02
	N	15.58
	O	23.56
Vegetable albumen, ...	C	54,74
	H	7.77(?)
	N	15.85
	O	21.64
Glutin, ...	C	55.22
	H	7.42(?)
	N	15.98
	O	21.38

The quantities of sulphur and phosphorus with which protein combines when forming the three substances in plants, have not been determined.

Legumin, precipitated by sulphuric acid from a watery infusion of beans, and the precipitate afterwards digested with ether, gave—

C	55.05
H	7.59(?)
N	15.89
O	21.17

pounds, which, when introduced into the animal body, transfer the protein to it unchanged. Hence, we may infer,

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These analyses have been repeated, more recently, by Dumas and Cahours (Annales de Chimie et de Physique, tome vi., 1842, p. 409.) With regard to vegetable albumen and glutin, their results do not differ from those obtained by Jones (see p. 409, 419, and 423). But for legumin from beans they found—

C	50.53	50.46
H	6.91	6.65
N	18.15	18.19
O	24.41	24.70

When bruised almonds are digested with cold water, a large quantity of a similar substance can be precipitated from the liquid by an acid. Dumas and Cahours found its composition to be as follows (p. 427) :—

C	50.94	50,93
H	6.72	6.70
N	18.93	18.77
O	23.41	23.60

This should, therefore, be the same substance as legumin. They obtained it likewise from plums, apricots, mustard-seed, &c. It is coagulated by rennet, though its composition remains the same.

If the analyses of Dumas and Cahours are correct, then those of Jones are not, and legumin would not belong to the series of protein-compounds, but would be analogous to gelatine (see below). In these cases, however, the correctness of Dumas and Cahours is not much to be relied upon. (Scheik. Onderz. Deel I., p. 553.)

Rochleder has since made analyses of protein from legumin. (Annalen der Chemie und Pharmacie, Bd. 46, S. 162.) The results obtained by him, differ from those which Jones, Dumas, and Cahours obtained for legumin.

C	54.49
H	7.40
N	14.78
O	23.33

Rochleder asserts, that legumin is similar to casein, differing from it only in its reaction with acetic acid. These analyses, however, have been made with protein from legumin, not with legumin itself. For Rochleder dissolved the legumin in strong potash, and precipitated the filtered liquid with acetic acid, so that it could no longer be legumin; but must have been changed into protein, being freed from sulphur, and at the same time mixed with another substance, the presence of which diminishes both the nitrogen and carbon at a rate of more than one per cent. The composition of legumin, therefore, is still unknown. According to Rochleder, legumin contains sulphur and a certain quantity of a substance, insoluble in potash and ammonia. But the legumin of almonds and peas does not contain any free sulphur.

that the changes, produced by animal digestion in these substances, in order to prepare animal constituents from them, are, *first*, that it dissolves the insoluble vegetable albumen and glutin; and, *secondly*, that it alters the quantities of sulphur and phosphorus—which probably exist in the vegetable protein-compounds, in other proportions than in those of the animal. With regard to glutin, this fact is proved.

It will not be superfluous here, to dwell shortly upon the properties of these vegetable protein-compounds.

1° Glutin and coagulated vegetable albumen may be obtained by kneading wheat-flour under water to separate the starch, and digesting the residue with alcohol. What remains undissolved, is *coagulated vegetable albumen*, still containing some starch, from which it may be separated by boiling in water. It contains also some *cellulose*. It cannot, therefore, be submitted to elementary analysis in this condition; for then we obtain the results of a mixture of vegetable albumen and cellulose. This is the reason why Jones (see note, page 296) obtained too little carbon from the substance he had prepared in this way.

We have no other means of separating the cellulose from the vegetable albumen in the above mixture, than by changing the albumen into protein, that is, by taking away the sulphur and phosphorus from the albumen. This can be done by potash. By a weak alkaline solution the protein is dissolved, and the phosphorus oxidized. From the sulphur, sulphuret of potassium is formed, and the cellulose remains

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Further experiments are, therefore, necessary to determine this point.

From *glutin* of wheat, separated from alcohol by cooling, redissolved in alcohol, separated anew and treated with ether, I obtained this result (Scheik. Onderz. Deel II.):—

	I.	II.	Atoms.	Calculated.
C	54.93	54.75	400	54.89
H	7.11	6.99	310	6.94
N	15.71	15.71	50	15.90
O	21.68	21.93	120	21.55
S	0.57	0.62	2	0.72

undissolved. By adding a weak acid to the clear solution, protein is precipitated.

No method has been discovered of obtaining pure coagulated albumen. In all seeds, in which it is present, it is mixed with cellulose, for which we do not know any solvent, which would not also take up the albumen; and if the albumen is dissolved and the cellulose left, the former is changed by solution into protein. Thus we are not yet acquainted with any pure, so-called, coagulated vegetable albumen; and it is thus equally unknown with what quantity of sulphur and phosphorus, the protein it contains is combined.

The substance which is dissolved from coagulated vegetable albumen by caustic potash, has the same properties as animal protein, obtained by dissolving cheese, fibrin, albumen from eggs, and that from the serum of the blood in a weak solution of potash. When mineral acids are added to this liquid, protein is precipitated and a little sulphuretted hydrogen is disengaged.

The property of being soluble both in potash and acetic acid, is possessed by all the protein-compounds, in common with the vegetable albumen, which we have called coagulated. These properties are accurately described in the work of Berzelius,* in treating of vegetable albumen, glutin, animal albumen, fibrin, casein, &c.

The substance, soluble in alcohol, which is left behind, after wheat flour has been kneaded with water, is called *glutin*. After the alcohol is cooled, mixed with water and distilled off, this substance is precipitated in the form of white flocks; another part of it, together with the gum, is kept in solution by the weak alcohol, even when it has been diluted with much water. When moist, it is very coherent, viscous and elastic; when dried, it is a semi-transparent substance, very hard, difficult to reduce to powder, and insoluble in water, and possesses all the properties of the compounds of protein with sulphur.

This compound is probably not a pure chemical body; for when acetic acid is poured upon the glutin obtained as

* Traité de Chimie.

above, though the greater part is dissolved, yet a small portion of a substance, insoluble in acetic acid, is left behind. This substance makes the liquid opaque, and cannot be separated by filtration.

We are thus, as yet, but imperfectly acquainted with the real character of glutin, although we know that it is a compound of sulphur with protein.

2° The *albumen* of plants has similar properties with those possessed by the animal albumen, from the serum of the blood, from eggs, and from several other bodies. It is obtained in a coagulated form from all fresh saps of plants, upon heating them. This is the form in which protein is chiefly prepared in plants, and from which the other protein-compounds they contain—for instance, the coagulated albumen—are probably produced. When coagulated from the saps of plants by heat, it contains chlorophyle and other substances.

It is obtained in a pure state from wheaten-flour, by heating the water with which the dough has been kneaded, after the starch has subsided. The albumen coagulates, and after being boiled with water and alcohol, is pure vegetable albumen. Its component parts are just the same as those of animal albumen, with the exception of the sulphur and phosphorus, the proportions of which have not been determined.*

3° *Legumin* is a substance very much like glutin, and is obtained chiefly from peas and beans. When the meal of those seeds is soaked in water, legumin is dissolved, and may be precipitated by an acid. The liquid in which it is dissolved has an acid reaction;—when separated it is insoluble in water. When dissolved in ammonia, precipitated again by an acid, and then treated with alcohol, it is pure. It is a compound of protein, but we do not yet know its exact nature.

In almonds a substance is found similar to legumin, which, though prepared in the same manner, has given different re-

* Adriani, in Scheik. Onderz. Deel I. p. 56.

C	54.78
H	7.34
N	16.01
O	21.87

sults by analysis. Almonds contain also a substance called synaptas, of which the composition is not that of a protein compound.*

It follows from this brief account of the four protein-compounds known to exist in plants, that two of them are soluble in cold water—namely, albumen and legumin, of which the former can be coagulated by heating the liquid in which it is contained, but not the latter;—and that the two others are insoluble in water, the so-called coagulated albumen and glutin, of which the latter is soluble in alcohol.

In the animal body similar substances are also found, which differ from each other by minute admixtures or combinations. As legumin and glutin differ from vegetable albumen, so does casein differ from animal albumen. There exists only an approximation in properties and composition between those bodies, and as long as we are unacquainted with these minute admixtures, we cannot know their real composition.

The protein-compounds contained in the animal body, as far as is yet known, are the following:—

Fibrin from blood, is composed after the formula—

$$10\ (C^{40}\ H^{31}\ N^{5}\ O^{12}) + S\ Ph.$$

Albumen from the serum of the blood—

$$10\ (C^{40}\ H^{31}\ N^{5}\ O^{12}) + S^{2}\ Ph.$$

Albumen from eggs, is the same as fibrin.

Casein, from cows' milk—

$$10\ (C^{40}\ H^{31}\ N^{5}\ O^{12}) + S.$$

The substance which forms the chief constituent of the crystalline lens of the eye—

* Richardson and Thomson have analysed an impure synaptas called *emulsine*, and have found its composition to be:—

C	49.025	48.556
H	7.788	7.677
N	18.910	18.742
O	24.277	25.026

Liebig, Chim. Organ., p. 135.

$$15\,(C^{40}\,H^{31}\,N^{5}\,O^{12}) + S.^{*}$$

These are all the protein-compounds of the animal body which are yet known. But the muscular fibre is also a compound of protein. The brain, the liver, the kidneys, and

* The analyses made by me in 1838, are the following (Bulletin, 1838, p. 108):—

	Fibrin from ox-blood.	Albumen from eggs.	Atoms.	Calculated.
C	54.56	54.48	400	54.90
H	6.90	7.01	310	6.95
N	15.72	15.70	50	15.89
O	22.13	22.00	120	21.55
Ph	0.33	0.43	1	0.35
S	0.36	0.38	1	0.36

	Albumen from the serum of the blood.	Atoms.	Calculated.
C	54.84	400	54.70
H	7.09	310	6.92
N	15.83	50	15.84
O	21.23	120	21.47
Ph	0.33	1	0.35
S	0.68	2	0.72

Casein from cow's milk (Bulletin, 1839, p. 9).

	Found.	Atoms.	Calculated.
C	54.96	400	55.10
H	7.15	310	6.97
N	15.80	50	15.95
O	21.73	120	21.62
S	0.36	1	0.36

Crystalline from the eye (Bulletin, 1839, p. 195).

C	55.39
H	6.94
N	16.51
O	20.91
S	0.25

The latter substance produces with sulphuric acid, sulpho-proteic acid, which gives 8.63 per cent. of sulphuric acid, that is, 1 equiv. for

$$C^{40}\,H^{31}\,N^{5}\,O^{12}.$$

From oysters, previously treated with water and alcohol, then dissolved in acetic acid and precipitated by ammonia, I obtained protein (Bulletin, 1839, p. 14):—

C	54.87
H	7.10
N	15.89
O	22.14

many other organs contain protein-compounds, in the form of albumen. Such compounds are likewise present in the serum, in the horns, nails, skin, and hair. Oysters consist almost entirely of protein-compounds, and they exist also in silk and

---

Finally, from silk, after the gelatine had been separated by boiling it in water, I obtained albumen, of which the composition was (Natuur-en Scheik. Archief. Deel IV. p. 287):—

C	54.01
H	7.27
N	15.46
O	23.26

Several of those substances have since been analysed by Scheerer (Annalen der Chemie und Pharmacie, Bd. xl., S. 1); the results of his analyses are quite the same. I do not mention those of Dumas (Annal. de Chim. et de Phys., tome vi., 1842, p. 385) because they exhibit no sign of accuracy.

Jones (l. c. S. 68) and Dumas and Cahours (l. c. p. 423) have analysed the yolk of eggs, after being freed from oil by ether, but they obtained different results.—

	Jones (C = 76.437.)		Dumas and Cahours (C = 75.)	
C	53.72	53.45	51.59	51.31
H	7.55	7.66	7.07	7.37
N	13.60	13.34	15.02	15.03
O	25.13	25.55	26.02	26.29

There seems to be no doubt that in this case they analysed impure albumen.

Such a difference of results, especially the smaller proportion of nitrogen found by Jones, made it necessary to analyse vitellin anew. This has been done by von Baumhauer. Yolks of eggs, boiled hard, were extracted with alcohol and ether. After being dried at 248° F. they gave—

O	52.99	52.95
H	6.93	6.92

Part of this substance was dissolved in acetic acid; the liquid filtered clear and precipitated by carb. of ammonia. The precipitate, after being extracted with alcohol and ether, and dried at 248° F., gave by analysis:—

	1st preparation.		2d preparation.
C	53.23	53.56	53.61
H	7.03	7.12	7.29
N	15.97	16.09	16.04
O	23.25	22.75	
S	0.52	0.48	

Below we shall see that vitellin is a sulphuret of bi-oxide of protein. $C^{40} H^{31} N^5 O^{12}$. To the product obtained by the latter method, which gives vitellin free from cellular matter,—not to be obtained from hard boiled yolks,—a little ammonia seems still to adhere, for the proportions of hydrogen and nitrogen are a little too high (Scheik. Onderz. Deel II.)

in the spider threads of autumn. The exact nature of these compounds, however, is unknown, as is that of vegetable albumen, legumin, and coagulated vegetable albumen. This is a gap in our knowledge which still remains to be filled up by science. The physical, and some of the chemical, differences which we observe in all those bodies, may arise from the presence of very small quantities of sulphur and phosphorus, and, perhaps, of other substances. We do not, therefore, regard all these bodies as identical, any more than we do starch and gum, though by analysis they give nearly the same composition in the hundred parts. But I would go further. Since we learn from experiment, that several of them contain different proportions of sulphur and phosphorus, we must hold the greater number of them to be in reality chemically different from each other. All of them, however, without exception, contain the same organic combination—protein—as a chief constituent. This constituent pre-exists in all of them, and thus enables the one to be easily transformed into the other.

It is of great importance to keep this in view, because nature, by adding a little to, or taking a little from, the same primary material, produces several bodies apparently very dissimilar. In this we behold a simplicity which is highly remarkable; but small as those quantities are, we find in the chemical difference of the substances added, the cause of the differences which exist in the nature and quality of the products. Thus the differences among the protein compounds above mentioned are by no means owing to polymorphism, but to a real chemical difference in their constitution. Therefore it still remains a problem, only to be solved by exceedingly laborious and carefully performed analyses,—in what respect, and how far those several protein-compounds are mutually different. It is for science not only to indicate that grass contains a protein-compound, from which ruminating animals obtain the protein-compound of which they daily yield a large quantity in their milk; but to determine whether the protein-compound in grass contains sulphur only, and no phosphorus, like that in milk; whether or not the proportions of

the constituents are different, and if so, how such differences are produced in the animal body. For it is as necessary to indicate by what cause the material difference between casein and albumen is produced, as it is important to know the nature of that difference. Since it is now a known and undisputed fact, that protein is prepared for animals by plants, these problems are among the first to be solved by science.

I speak the more emphatically on this subject, because I do not believe that those minute admixtures of sulphur and phosphorus are of little consequence; but on the contrary, that those bodies, notwithstanding their very minute quantity, perform a very important part in the organism. The character of the differences is not determined by the relative quantities of the constituents, but by their presence or absence. Arseniuretted hydrogen (H^3 As), which is one of the most poisonous gases, contains 98.05 per cent. of arsenic, and only 1.95 of hydrogen. It is to this small quantity, however, that the peculiar character and gaseous appearance of this compound are owing.

It is not yet known how the sulphur and phosphorus in these compounds are combined with protein. It is known, however, that the combinations are constant. It is true, therefore, that in fibrin, for instance, either 20 equiv. of protein are combined with a small portion of another substance, containing 1 equiv. of phosphorus, and 2 equiv. of sulphur, (which substance in the ultimate analysis of fibrin escapes our attention,) or one of phosphorus and one of sulphur, are really combined with 10 equiv. of protein. Either of these suppositions is equally a deviation from what we usually perceive in the greater part of inorganic combinations, and therefore, we are at present entitled to assume that the simpler of the two is the true one,—that is, that phosphorus and sulphur (S Ph) are really combined with 10 equiv. of protein. Protein, however, is not peculiar in this respect. One equivalent of alum, for instance, contains 24 equiv. of water of crystallisation.

We cannot as yet put the question, whether protein is first formed, and is then combined with phosphorus and sul-

phur, or whether its constituents separately combine with phosphorus and sulphur. Like amygdalin, protein is a complex body, consisting of several others; and therefore it is probable, that such a division of phosphorus and sulphur among its constituents does take place. It is certain, however, first, that protein can exist without sulphur and phosphorus; secondly, that there are some combinations, in which 10 equivalents of protein combine with one equiv. of phosphorus, and one of sulphur (Ph S); others, in which they combine with one of phosphorus, and two of sulphur (Ph S^2); others again, in which 10 and 15 equivalents of protein combine with one of sulphur (S). As far as they are yet known, these compounds are as follows:—

Crystalline, ...	15 protein	+	S
Casein, ...	10 —	+	S
Glutin, ...	10 —	+	S^2
Fibrin, ...	10 —	+	S Ph
Albumen from eggs,	10 —	+	S Ph
Albumen from serum of the blood, ...	10 —	+	S^2 Ph

These compounds of protein with sulphur and phosphorus, or with sulphur alone, form interesting combinations with acids, bases, and salts. Protein itself combines with oxygen. Two of these compounds are known: one of them is prepared from chlorite of protein, by the action of ammonia, by which sal ammoniac is produced, and a substance called tri-oxide of protein is at the same time formed. It can also be obtained by boiling fibrin and albumen in water. It is a chief constituent of inflammatory crusts. A small quantity of it always exists in the blood, and it is produced in the lungs. Its formula is $C^{40}\,H^{31}\,N^5\,O^{15}$.

The other may be obtained by dissolving hair in potash, and precipitating by an acid. The first substance precipitated is protein; the second, bi-oxide of protein, $C^{40}\,H^{31}\,N^5\,O^{14}$.

The 2 equivalents of sulphur in the hair, combine with the potassium of the potash-solution, in which the hair is digested, and thus 2 equivalents of oxygen are set free, which combine with the protein, and change O^{12} into O^{14}, all the

other constituents remaining unchanged. By precipitating this bi-oxide of protein from the sulphuretted alkaline solution, sulphuretted hydrogen is disengaged, water at the same time being decomposed—two of hydrogen (H^2) combining with two of sulphur (S^2), and two of oxygen (O^2) with two of potassium (Ka^2); so that from 2 (Ka S) and 2 (H O), 2 (H S) and 2 (Ka O) are produced. (See below.)

These compounds of protein and oxygen are important substances. In the animal body they may by turns either be produced or decomposed. Scheerer* remarked, that moist fibrin, when exposed to oxygen gas, absorbed more oxygen than it evolved of carbonic acid. In this case a compound of protein and oxygen may therefore have been produced. This has indeed recently been confirmed. When fibrin is boiled in water, bi-oxide of protein is left undissolved, and tri-oxide of protein is dissolved by the water. (See below.)

The composition of chlorite of protein obtained from albumen, &c.—on passing chlorine through the liquid, by which water is decomposed—(C^{40} H^{31} N^5 O^{12} + Cl O^3), is so constant, that we can accurately calculate the atomic weight of protein from it. It gives us exactly the same result as sulpho-proteic acid. This combination does not exist in the body, but the knowledge of it is of importance in the art of bleaching, in the disinfecting of animal substances, in the use of chlorine in surgery, &c.

From the existence of an analogous gelatine-compound, we can have no doubt that this chlorite is really chlorite of protein, and not a chloride of tri-oxide of protein.

The combinations of sulpho-phospho-protein (fibrin, albumen) and of sulpho-protein (casein) with alkalies, acids, and salts, are especially remarkable. Protein is soluble in weak alkalies. Since, therefore, the serum of the blood is always slightly alkaline,—being a proteate of soda (with sulphur and phosphorus),—it keeps the sulpho-phospho-protein in solution. This property is the cause of the blood remaining in a liquid state—a chief requisite for animal life.

If a weak alkaline solution of protein is neutralised by

* Annalen der Chemie und Pharmacie, Bd. xl. S. 13.

an acid, the solubility of sulpho-phospho-protein is greatly diminished; a fact which throws light upon the medical properties of some acids. The sulphuric and phosphoric acids, for example, possess the property of stanching blood. Acetic acid, on the contrary, by which protein is readily dissolved, is destitute of that property. By very diluted hydrochloric acid, and also by acetic acid, fibrin is easily dissolved; the former is present in the chyle, the latter renders meat tender, and assists digestion. If solid protein-compounds, viz., fibrin and albumen, are kept for some time in exceedingly diluted hydrochloric acid—1 part in 2000 parts of water, for instance—they are completely dissolved, the presence of no other substance being requisite. This property throws much light on the function of the free hydrochloric acid in the chyle (Bouchardat).*

Some acids form chemical compounds with sulpho-phospho-protein. Of sulphuric and hydrochloric acid, for instance, large quantities combine with it, and produce, in certain circumstances, less soluble compounds. For this reason, they are very effective medicines in putrid fevers, scurvy, &c. These compounds are—

$$(C^{40}\,H^{31}\,N^{5}\,O^{12}) + S\,O^{3}.$$
$$2\,(C^{40}\,H^{31}\,N^{5}\,O^{12}) + 2\,HO + S\,O^{3}.$$
$$2\,(C^{40}\,H^{31}\,N^{5}\,O^{12}) + 2\,HO + H\,Cl.\dagger$$

* See Scheikundige Onderzoekingen, Deel I., p. 576.

† Bulletin, 1839, p. 21.

Bi-sulpho-proteic acid.

	Found.	Atoms.	Calculated.
C	51.61	80	51.87
H	6.75	64	6.78
N		10	15.02
O		26	22.06
$S\,O^3$	4.17	1	4.25

Bi-hydrochloro-proteic acid.

	Found.	Atoms.	Calculated.
C	51.49	80	52.09
H	6.80	64	6.81
N		10	15.08
O		26	22.14
H Cl	3.80	1	3.88

Both have been prepared by dissolving coagulated albumen in acetic acid, adding either sulphuric or hydrochloric acid, and washing the precipitate with alcohol.

It has been demonstrated by Hruschauer, that the two latter combinations, if allowed to remain under water for six weeks, lose all their acid, if prepared from uncoagulated, but not if prepared from coagulated albumen.*

Finally, sulpho-phospho-protein combines with some basic salts. The combination of this kind, which is found in casein, is particularly remarkable. It contains phosphate of lime, in the state of bone-earth, 3 Ph O^5 + 8 Ca O,—a salt which probably also occurs in fibrin and albumen (at all events a phosphate of lime does), and through these is supplied to the bones.† In casein (and also in milk) it exists in large quantity, and serves to supply, in a short time, much bony matter to the tender bones of young animals. Metallic salts and oxides, introduced into the body either as medicines or as poisons, can also combine with the protein-compounds and produce a variety of proteates (with sulphur and phosphorus), which must necessarily have peculiar effects in the body. The greater part of those combinations are insoluble, and so tend to check the incessant chemical change of materials in the organism. From this cause, peculiar conditions of the body must arise, which are noxious to life, if they are excited to a high degree. For this reason—though not for this reason only—salts of silver, lead, mercury, copper, &c., are poisonous, if a large quantity of them be introduced into the body.

Protein is a complex substance, that is, it consists of several heterogeneous organic compounds, united into one whole. Acted upon, therefore, by strong re-agents, it produces a variety of substances.

If a protein-compound be brought into contact with an alkali, ammonia is immediately disengaged. The alkaline solution can hardly be made weak enough to prevent the disengagement of ammonia. If either fibrin or coagulated albu-

* Annalen der Chemie und Pharmacie, Bd. xlvi. S. 348.

† It was Berzelius who first determined the composition of the phosphate of lime of bones to be such as is represented by the formula in the text. The same chemist, however, has lately thrown a doubt upon his former conclusion, and thinks it not improbable that as it exists in bones, it may have the composition represented by 3 Ca O + $P O^5$, a formula, which, for other reasons, is the more probable of the two.—*J.*

men be dissolved in a weak potash ley, ammonia is always perceptible. This is a property of the highest importance, in connection with the alkaline nature of the blood. It explains a chief characteristic of protein in the animal body, namely, that it is in a state of continual decomposition.

If either albumen, or any other protein-compound, is boiled with potash, it is completely decomposed. The products of this decomposition are certainly not *all* actual constituents of protein, but *some* of them must undoubtedly be considered as such. They are the following:—

	C	H	N	O
2 equiv. of leucin, ...	24	24	2	8
2 — of protid, ...	26	18	2	8
2 — of erythroprotid,	26	16	2	10
4 — of ammonia, ...	0	12	4	0
2 — of carbonic acid,	2	0	0	4
1 — of formic acid, ...	2	1	0	3
2 equiv. of protein, + 9 equiv. of water ...	C^{80}	H^{71}	N^{10}	O^{33}

Leucin is a crystalline substance which can also be obtained from gelatine, and thus indicates a connexion between the composition of protein and substances which produce glue.* It may be obtained, under very different circumstances, either with or without gelatine-sugar, from fibrin, albumen, casein, gelatine. From rotting cheese, for instance, and by boiling albumen, fibrin, and casein, with potash, nothing but leucin is produced. Gelatine-sugar is procured by treating glue with sulphuric acid; and a mixture of both is obtained by treating meat with either sulphuric acid or with potash, or by treating glue with potash. Leucin and gelatine-sugar,† there-

* Bulletin, 1838, p. 145.
The composition of leucin is—

			Atoms.	Calculated.
C	55.64	55.53	12	55.79
H	9.30	9.32	12	9.11
N	10.51	10.51	1	10.77
O	24.55	24.74	4	24.33

† See the note at page 233.

fore, are nearly allied substances, as to their origin. Leucin may be considered as a constituent part of protein.

The two other compounds, protid and erythroprotid (the latter of which is of a red colour), are extractive substances, and closely related to gelatine.*

As to the three remaining products of decomposition from protein by potash, the two acids combine with the potash, and the ammonia is disengaged.

This decomposition of protein by alkalies cannot explain any phenomenon in the living organism, until it has been demonstrated either that leucin exists in the animal body, or that it is employed in some secretion. The analogy, however, that exists between the two extractive compounds and gelatine, deserves particular attention, and renders it probable that if the animal cellular tissue is produced from protein, a change is effected similar to that which takes place under the influence of alkalies. We shall treat of this subject more fully when we come to speak of the cellular tissue in animals.

We have still to consider in what form protein exists in the animal body. Since it is supplied to animals by plants, and always in combination with sulphur and phosphorus, or with these and phosphate of lime, vegetable food is never pure protein any more than animal food. Our almost total ignorance of the quantities of sulphur and phosphorus, which are present in the protein-compounds of plants, is a great disadvantage, and so long as it continues, we can say nothing certain as to the production of animal protein-compounds from those of plants, but that the protein of vegetable food passes into the animal unchanged. The production, how-

* Bulletin, 1838, p. 167.

Protid.	Found.	Atoms.	Calculated.
C	59.20	13	59.04
H	6.62	9	6.67
N	10.56	1	10.52
O	23.62	4	23.77
Erythroprotid.			
C	56.63	13	56.12
H	5.93	8	5.64
N	10.23	1	10.00
O	27.21	5	28.24

ever, of albumen in the serum of the blood, of fibrin, casein, &c., requires a fuller explanation, since those protein-compounds do not probably occur in that state in plants.

We are acquainted with different kinds of protein-compounds in the animal body—in combination, for example, with sulphur; with sulphur and phosphorus; with sulphur, phosphorus, and alkalies; with sulphur and phosphate of lime; and lastly, with oxygen.

The serum of the blood holds in solution a compound of sulphur, phosphorus, and protein, which has very much the same properties as vegetable albumen and the albumen of eggs. It is in this form chiefly, that protein is frequently found in the animal body. It is called albumen. In every organ, in every liquid (being not a secretion) which is analysed, this substance is always found. If, for instance, an organ, cut to small pieces, (a piece of the liver, kidney, or lung,) is kneaded with water, albumen, coagulable by heat, is obtained. It is found in the lymph of the lymphatic vessels, in perspired serum, in chyle, in pus. It is still unknown, whether in all these sorts of albumen the same substance represented by—

$$10\ (C^{40}\ H^{31}\ N^{5}\ O^{12}) + Ph\ S^{2}$$

be always existing. It is not even probable that this is the case.

A large quantity of a substance, similar to albumen, is found in the brain, spinal marrow, and nerves. It is, however, somewhat more solid, so that, being less easily soluble in cold water, it seems to bear more resemblance to the insoluble albumen of oily seeds. When a portion of brain is rubbed with water, an emulsion, similar to that of oily seeds, is obtained. Neither is the composition of this brain-protein-compound known. It may be sufficient to class them all under the name of albumen, till we shall have learned more of their nature.

Slight differences in the proportion either of sulphur or of phosphorus, produce a considerable difference in the nature of the protein-compound. Hence casein and fibrin do really differ as much from the albumen of the serum, as these albuminous bodies which are coagulable by heat, differ from

each other. They cannot, therefore, be considered as identical.

In milk, along with the fats, there exists a compound of protein with sulphur, free from phosphorus. This compound is casein, which has the peculiar property of being precipitated from its solution in water by rennet and by the acids, especially by the lactic acid.

Casein has been found in several other animal liquids, for instance, in the saliva, the gall, the pancreatic juice, the crystalline lens, pus, the matter from tubercles, and what is of most importance, in the blood. As, however, all the accounts of its existence in the blood are based only on the discovery of its properties, and not on analyses, entire dependence cannot be placed upon them. It would, however, not be strange, if casein really existed in blood; for it may easily be produced either from the albumen, or from the fibrin contained in the serum,—it being only necessary to withdraw the phosphorus. When, therefore, casein is secreted from the blood, in the production of milk, nothing else takes place but the retention of phosphorus.

This is also the case in the formation of crystalline, which in like manner contains no phosphorus, and less sulphur than fibrin,—much less than the albumen in the serum. All these substances, and perhaps the whole series of albuminous bodies in the brain, liver, kidneys, &c., are produced either from the albumen, or from the fibrin in the blood, by a very slight change in the proportions of sulphur and phosphorus.

With regard to the fibrin in the blood, we have first to remark, that it does not exist in that fluid in its *fibrous* state. It constitutes the fibres of the muscles, the chemical composition of which is known to be that of a protein-compound, though we are not yet perfectly acquainted with its nature. Since the properties of this muscular fibrin agree with those of the fibrin in blood, we are induced to suppose that they are chemically identical.

We know that fibrin appears in the blood when it coagulates. After this coagulation the blood contains thread-shaped bodies, which were not to be found in it before. Fi-

brin is said to be *dissolved* in blood. This expression, however, cannot be taken literally. It is more likely that fibrin exists in the blood in a semi-fluid state.

We shall recur to this hereafter, when speaking of blood. It may be sufficient here to remark, that fibrin does not exist in blood in the form of little threads, but by its coagulation becomes a jelly, which unites into small threads during the washing out of the blood. This alone makes it improbable that fibrin is dissolved in the blood. Its particles must be entirely isolated from the dissolved albumen in the circulating blood, as there is a difference between them, of 1 equivalent of sulphur in every 10 equivalents of protein.

The blood contains a third protein-compound still,—that which constitutes the cellular film of the globules in the blood. For this reason it is called *globulin*. Simon thinks it is casein. It is unquestionably a protein-compound;* but its real composition is not yet known. Neither do we know the nature of the substance which is found in the centre of the blood-globules, nor that of the liquid, which, along with the colouring matter, is enclosed within the film.

All these compounds of protein in the animal body contain different quantities of phosphate of lime. The same substance, taken from different animals, contains also different proportions of this salt.

Two other very important protein-compounds, occur in the bodies of animals, namely, the *bi* and *tri-oxides* of protein. They both exist, to a large extent, in inflamed blood. They are produced during respiration, and are ordinary constituents of blood. The latter is soluble in water, the former is not. They are both produced by oxidation, when fibrin is boiled in water. The tritoxide is also formed, when albumen is boiled, and is a product of the decomposition of the chlorite of protein† (see p. 304); the bi-oxide can be obtained from hair by the action of an alkali.

Both, as I have said, are found in the blood, being constitu-

* Bulletin, 1839, p. 84.

† Bulletin, 1839, p. 404, and Scheikundige Onderzoekingen, Deel I., p. 259 and 550:—

ents of the healthy organism. In it, upon every respiration, a small quantity of them is produced, and they probably form round the blood-globules a thin layer, which has the same

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The *tritoxide* of protein.

	I.	II.	III.	IV.
C	51.47	51.69	51.38	51.48
H	6.60	6.64	6.78	6.56
N	15.37	15.09	15.01	
O	26.56	26.58	26.82	

No. I. was prepared from chlorite of protein, of which the chlorine had been removed by ammonia.

No. II., by boiling fibrin in water.

No. III., by boiling albumen in water.

No. IV., from an inflammatory crust. It is soluble in water.

	Atoms.	Calculated.
C	40	51.45
H	32	6.72
N	5	14.92
O	16	20.93

Bouchardat has called this substance gelatine (Annal. de Chimie et de Phys. 1842, tome vi. p. 440).

Binoxide of protein.

	I.	II.	III.
C	53.69	53.64	53.44
H	6.90	6.88	7.04
N	15.63	15.85	14.51
O	23.71	23.64	25.01

	Atoms.	Calculated.
C	40	53.36
H	31	6.75
N	5	15.45
O	14	24.44

I. was obtained by boiling fibrin in water; it then remains behind insoluble.

II. is the albuminose of Bouchardat (Comptes Rendus, 20 Juin, 1842). Von Baumhauer, in Scheikund. Onderzoek., Deel I., p. 568.

III. was obtained from hair, by dissolving it in potash. If a little acid is first added, the protein is precipitated; and by then adding a large excess of acid, binoxide of protein is obtained (see Scheikund. Onderz., Deel I., p. 167). The composition of protein from hair is as follows:—

	Scheerer.		Van Laer.
	From hair.	From horn.	From hair.
C	54.75	55.41	54.38
H	7.13	7.24	7.03
N	15.73	15.59	16.91
O	22.39	21.76	21.68

composition as the inflammatory crust. We shall explain this more fully when treating of the colouring matter of blood.

They are produced by the oxidation of the substance, which, during the coagulation of blood, is changed into fibrin. This protein-compound absorbs oxygen in the lungs, and circulates through the arteries in the state of the two oxides of protein. They are decomposed in the capillary system, and are employed in effecting the necessary changes in the substance of the body. If too large a quantity of these oxides be present, inflammation ensues.

Tritoxide of protein is contained in pus; it is called *Pyïne* by some; binoxide of protein constitutes some tissues, which we shall afterwards describe. Vitellin we have recognised (p. 301, *note*) as bi-oxide of protein.

It cannot be stated with certainty, in what way and under what circumstances protein is prepared by plants. When examining mould-plants of the lowest formation, I always found protein present in them; this was, as we shall afterwards see, produced from substances containing no nitrogen, when dissolved in water, and exposed to pure atmospheric air. In the very youngest radical fibres of plants, protein is present. Thus, together with dextrin and cellulose, it is among the substances first produced by plants. No organisation in the vegetable kingdom seems to be possible without the aid of protein. It gives activity to the cellular-membrane, and, though this membrane can be freed from protein by alkalies, it is nevertheless a component part of all new cells in plants.

As it is certain, therefore, that dextrin, cellulose, and protein, are all directly produced from the substances by which plants are fed, so it is probable that the whole of the protein present in the plant, is produced at the very extremities of the radical fibres. Hence the reason why (in a soluble state) it can penetrate along with dextrin through the cells already produced to form elsewhere new cells, which are a combination of cellulose and protein, in what seems a definite proportion; or after having been deposited here or there in a solid form, it may be rendered soluble by other substances such as have already been mentioned (p. 287), and thus trans-

ferred to some other place. We draw this inference, because to many plants a small quantity of protein is sufficient, though it is indispensable to the formation of every new series of cells. If we consider how large a proportion of it is present in young cells, and how small a proportion in such as are old, it will appear that the same quantity of protein must be employed in the same plant for an infinite variety of different purposes, being produced at the extremities of the roots, deposited at one place, and thence again taken up, and transferred elsewhere.

It may also be assumed, that this protein is seldom entirely consumed in plants. It appears, however, that it is employed in the formation of the vegetable alkalies and other nitrogenous bodies in some natural families; while in others, chlorophyle, indigo-matter, &c. are, no doubt, produced from it.

Fibroïn.

If either silk or the threads of the autumn spider (gossamer threads) are boiled with water, and then with strong acetic acid, till the whole of the gelatine and albumen are dissolved, small brittle threads are left, entirely different from the protein-compounds known to exist in animals of the higher classes. These threads have the following properties:—they have lost almost all their cohesion, are soluble in strong sulphuric acid, are precipitated from the diluted acid by an infusion of galls, and are soluble in nitric and hydrochloric acids; they are not acted upon either by acetic acid or by ammonia, but they are taken up by potash, and at the same time decomposed into different substances. Their composition is—

$$C^{39} H^{31} N^6 O^{17} = 3 (C^{13} H^{10} N^2 O^5) + H O + O$$ *

that is, 3 equivalents of gelatine with one of water, and one of oxygen.

* Natuur-en Scheikundig. Archief., D. III. p. 93; D. V. p. 281.

Fibroïn from silk.

	I.	II.	III	IV
C	41.97	48.08	49.11	49.27
H	6.81	6.50	6.50	6.50
N			17.67	17.02
O			26.72	27.21

It is very remarkable that sponge has exactly the same composition and properties as this fibroïn from silk, except that it is combined with sulphur, iodine, and phosphorus. According to the analysis of Croockewit, sponge consists of fibroïn combined with sulphur, iodine, and phosphorus. It is represented by

$$C^{780}\,H^{620}\,N^{120}\,O^{340} + I\,S^3\,Ph^5$$
$$= 20\,(C^{39}\,H^{31}\,N^6\,O^{17}) + I\,S^3\,Ph^5$$

that is, 20 of fibroïn combined with 1 of iodine, 3 of sulphur, and 5 of phosphorus, in the same manner as protein combines with sulphur and phosphorus, to form fibrin, albumen, &c.

This substance secreted in the shape of threads, which we know to form the inner part of gossamer threads and silk, is probably to be reckoned among the more important constituents of the body among the lower animals. Perhaps it takes there the place of the fibrin in the blood of the higher animals. We

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	Atoms.	Calculated.
C	39	48.64
H	31	6.31
N	6	17.32
O	17	27.73

Scheikundige Onderzoekingen, Deel II. p. 1.

Sponge.

	I.	II.	III.	IV.	V.
C	47.14	48.01	46.91	47.20	47.35
H	6.34	6.35	6.38	6.51	6.33
N	16.23	16.06			
O	26.52	26.40			
I	1.11	1.05			
S	0.53	0.46			
Ph	2.13	1.67			

	Atoms.	Calculated.
C	780	47.04
H	620	6.10
N	120	16.76
O	340	26.82
I	1	1.24
S	3	0.48
Ph	5	1.56

Thus it is very likely that 20 equiv. of fibroïn, *i. e.* the substance which constitutes the inner part of the silk thread, are combined with one of iodine, three of sulphur, and five of phosphorus.

have still, however, but a very limited acquaintance with this substance, because we only know it as a secretion; and as regards the sponge, an animal of the very lowest order, it stands too entirely alone to afford any ground for a general conclusion. We therefore mention the fibroïn only in passing. In order, however, to become acquainted with the transformations of substances in the animal body, we ought especially to investigate the constituents of the simply organized animals. We know almost nothing as yet of the chemical substances contained in insects, though that order of animals, from its peculiar characters, is of more importance than many of the others.

It remains to be decided by future investigations, whether the connection between fibroïn and gelatine, indicated by one of the preceding formulæ, really exists.

Gelatinous Substance—Gelatine, Chondrin.

Among the component parts of organized nature, none occurs more frequently than the cell. It is the base of all the distinguishable forms of organized bodies. Nature, by subjecting it to innumerable modifications, produces all the variety exhibited by plants and animals in the external form, in the structure, and hence, also, in the functions of their organs.

In the formation of these cells in plants, as well as the parts derived from them, nature employs one general material, $C^{24}H^{21}O^{21}$ (cellulose). Although in this substance others are deposited by which the nature of the cell is altered, yet this single substance,—cellulose, or woody fibre,—is employed as the material, in combination with a little protein, out of which the cells of plants are formed.

This is almost equally the case as regards animals, though both the elementary form of the tissue and its chemical characters are different. In animals, we must distinguish between the permanent and the primary cellular substance. It is probable that the primary has various characters, those of the permanent being universal. In different organs the primary varies, and is gradually supplanted by the general or permanent substance in which other substances will be afterwards de-

posited, in such a way as to obliterate entirely its cellular form.

For this general permanent substance, therefore, we have to look in animals and in organs which are fully developed. In the higher animals it constitutes by weight the larger proportion of the animal substance. It is a secondary product, and thus differs from the cellular substance in plants, which is a primary one; neither has it a real cellular shape like the latter. It has, however, several points of resemblance to it, especially in regard to the large proportion in which it exists in the body, and to the several functions which it performs.

Hence, also, a great many animal substances, when analysed, are found to consist of nearly the same constituents. This general animal substance is so universally diffused through the body, that it would exhibit the entire shape of the body, and of its principal parts, though all the other substances were separated. It constitutes the skin, the serous membranes, the ligaments of the muscular fibres, the organic part of the bones, and many other substances. (See *Ligamentary Tissue.*)

As yet, few of the properties of this substance are known. It is insoluble in cold water; acetic acid renders it transparent and bulky; tannic acid renders it solid, and preserves it from putrefaction,—and it produces a jelly by boiling. Attention was at first directed especially to the latter property, and hence the substance received the name of gelatine.

Every substance from which a jelly is procured by boiling, however, does not consist of the same animal tissue. There are, on the contrary, many dissimilar tissues, which are changed into a jelly by boiling.

The chief mass of the tissues, which produces a jelly on boiling,—that general substance, the use of which is analogous to that of cellulose,—we would call *gelatine.*

When boiled in water, nearly the whole of this substance becomes soluble in water. An air-bladder, for instance, when repeatedly boiled with water, leaves, according to the experiments of Cop, only 1.7 per cent. of insoluble vascular coats.*

The same is the case with every other substance, con-

* Scheikund. Onderzoek., Deel I. p. 67.

sisting of ligamentary tissue; and thus these bodies may be considered, in a chemical point of view, as formed of gelatinous matter; in other words, of matter which is changed almost entirely into gelatine by boiling. During that process, its composition remains unaltered. For when any serous membrane is analysed by means of combustion, nearly the same composition in the hundred parts is obtained, as when the gelatine or jelly, produced from this membrane by boiling, is submitted to analysis. The same holds good with regard to the skin,—to the ligamentary tissue, which unites the skin with the subjacent parts, and in which the fat is commonly deposited—to the ligaments of the muscular fibres, the substance in the bones by which the salts are taken up, and many other parts of the body, which we shall afterwards mention, when treating of the tissues.

The gelatinous substance in all those parts is insoluble in cold water, and by boiling is merely physically altered, without undergoing any chemical change. During the boiling nothing is either taken up or separated. In this instance, then, we observe an alteration analogous to that of starch, when changed by heat and water into starch-mucilage. It is possible, that by this process the atomic weight of the substance may be altered by a polymeric transformation.

There exists, however, a secreted gelatinous matter, namely, that in silk and gossamer threads, which is soluble in cold water. It was formerly called *gum* by Roard, and the process of separating the silk from this gelatinous envelope has long been called the *un-gumming*. This, so far as we know, is the only instance of a gelatinous substance of the animal body, which is soluble in cold water. It is likely, however, that it exists in blood in a state of solution. Whenever gelatine forms a part of the solid substances of the body, it is insoluble in cold water, and it can be dissolved out of these substances by water at the boiling temperature. Its composition is,

$$C^{13}\,H^{10}\,N^{2}\,O^{5},$$

whether obtained from jelly of hartshorn, from isinglass,

or from silk.* Both the unboiled and the boiled cellular matter, after it is changed into glue, combine with tannic acid, and produce compounds which are insoluble in water,

* From the following species of gelatine, I obtained (Bulletin, 1839, p. 24):—

	Gelatine from hartshorn. I.	Gelatine from hartshorn. II.	Gelatine from silk.
C	50.05	50.05	40.49
H	6.48	6.64	6.36
N	18.35	18.39	19.19
O	25.12	24.92	24.96

	Gelatine from isinglass.	Atoms.	Calculated.
C	50.76	13	50.37
H	6.64	10	6.33
N	18.31	2	17.95
O	24.29	5	25.35

Cop found that by boiling isinglass, only 1.7 per cent. was left insoluble; this portion gave (Scheik. Onderz. D. I. p. 67)—

C	52.02
H	6.71

This is the reason why Scheerer obtained by the ultimate analysis of entire and unaltered air bladders, almost the same results as those given above from the jelly. He found (Annalen der Pharmacie, Bd. 40, S. 46):—

	Isinglass.	Tendons.	Sclerotica.
C	50.56	50.96	51.00
H	6.90	7.19	7.08
N	18.79	18.32	18.72
O	23.75	23.53	23.20

There are three combinations of gelatine with tannic acid, two of which I formerly analysed (Bulletin, 1839, p. 23)—

$$C^{13} H^{10} N^3 O^5 + C^{18} H^5 O^9 + 2\,Aq.$$
$$3\,(C^{13} H^{10} N^3 O^5) + 2\,(C^{18} H^5 O^9 + Aq.)$$

Schiebel found that 100 parts of gelatine combined with 59.25, 88.9, or 118.5 parts of tannic acid, which are equal to 1 equivalent of gelatine with 1, 1½, and 2 equivalents of tannic acid.

Thus the formula for gelatine is now fixed. It has, however, been determined in two other modes. First, by passing a current of chlorine through a solution of gelatine, by which chlorite of gelatine is produced (Bulletin, 1839, p. 153).

We know three combinations of this kind, consisting of 1 equivalent of gelatine, and 1 equiv. of Cl O^3 (chlorous acid), 3 equiv. of gelatine and 2 equiv. of Cl O^3, 4 equiv. of gelatine, and 1 equiv. of Cl O^3. The latter of these is as constant in its composition as any chemical compound which can be obtained, and thus no room is left for doubt as to the atomic weight and the formula of gelatine.

The following are the analytical results:—

and resist putrefaction. Hence the power of all substances containing tannic acid to restore weakened energy in the organism. Protein compounds and gelatine both produce hard and coherent compounds with tannic acid. Similar compounds are also formed in the organism by Peruvian bark, willow bark, catechu, and many other astringent medicines. Only a small quantity, however, of this abundantly supplied tannic acid is carried into the blood,—otherwise it would destroy the vital action. If the quantity of tannic acid contained in 1 ounce of Peruvian bark, or even in a much smaller portion of it, were carried into the blood, immediate death would most certainly ensue, for it would make the greater part of the albumen in the blood coagulate. This is also the case with alcoholic liquids, by which gelatine and the protein compounds are precipitated; and also with alum, which renders gelatine solid,—the latter being precipitated in combination with the alumina, upon the addition of alkalies.

	Found.		Atoms.	Calculated.
C	46.66	46.25	52	46.52
H	5.90	5.81	40	5.84
N	15.59		8	15.54
O	23.37		20	23.41
$Cl O^3$	8.48	8.47	1	8.69

Scheerer found more hydrogen than I did in analysing gelatine; therefore my experiments have recently been repeated by Van Goudoever (Scheik. Onderz. D. I. p. 257). He analysed gelatine, after long ebullition, by which its property of forming a jelly is destroyed. The result was:—

	Found.		Atoms.	Calculated.
C	49.50	49.56	52	49.67
H	6.56	6.54	41	6.39
N	17.36	17.36	8	17.69
O	26.58	26.54	21	26.25

that is, a hydrate, analogous to the latter chlorite—

$$4\,(C^{13}H^{10}N^2O^3) + Cl\,O^3$$
$$4\,(C^{13}H^{10}N^2O^3) + Aq.$$

Thus gelatine, after long ebullition, has an atomic weight, which is quadruple of that which it possesses when it forms a jelly. When chlorine was passed through the solution, I obtained a fourth combination of gelatine with chlorous acid, consisting of 5 equiv. of gelatine and 2 of chlorous acid, $Cl\,O^3$ (Scheik. Onderz., D. I. p. 523).

From the production of leather by substances containing tannin, we learn that the cellular tissue contains gelatine in the state of a hydrate, of which the water can be replaced by the tannic acid, the product being the tannate of gelatine, which is hard, insoluble, and resists putrefaction.

There are three tannates of gelatine, containing respectively 1 equivalent of gelatine, and 1 of tannic acid; 2 equivalents of gelatine, and 1 of tannic acid; 3 equivalents of gelatine, and 2 of tannic acid.

If chlorine is passed through a solution of gelatine, a precipitate is obtained, of which the composition, after drying, is

$$4\,(C^{13}\,H^{10}\,N^2\,O^5) + Cl\,O^3.$$

Before drying, however, the precipitate contains two compounds, consisting respectively of 1 equivalent of gelatine, with 1 of $Cl\,O^3$ (chlorous acid), and 3 equivalents of gelatine, with 2 of $Cl\,O^3$.

When ammonia is added to this compound, the solution evaporated, and the sal-ammoniac it contains removed by alcohol, a hydrate of gelatine is obtained, which no longer gelatinizes. Its composition is,

$$4\,(C^{13}\,H^{10}\,N^2\,O5) + Aq.$$

The same product is obtained by boiling gelatine in water for a long time. This peculiarity ought to be kept in view, when meat is boiled for a long time into bouïllon, and especially when victuals are prepared in Papin's digester, because it is doubtful whether this hydrate can be again changed into food by the organism, and whether it may not produce noxious substances in the body.

Plants probably do not prepare gelatine, since it has not hitherto been found in vegetable food.

It is not yet known how the gelatinous tissues are produced in the animal body. Many conjectures may be formed, but we have no certain knowledge upon the subject. There are some substances, however, in the organism, of which the composition is analagous to that of gelatine; others are formed from protein by means of alkalies (p. 310). The latter peculiarly deserve our attention, because the serum of the blood is alkaline, and contact with even the weakest alkaline

solution causes protein to be decomposed, as we have mentioned at p. 309. It appears to be certain, from its absence in vegetable food, that the gelatinous matter is formed in the animal body.

Hair contains, along with sulpho-protein ($C^{40}\ H^{31} N^5\ O^{12} + S^2$), a ligamentary substance, $C^{13}\ H^{10}\ N^3\ O^5$, which differs from gelatine by containing 1 equivalent of nitrogen more. The composition of protid, $C^{13}\ H^9\ N\ O^4$, and that of erythroprotid, $C^{13}\ H^8\ N\ O^5$, also very nearly approximate to that of gelatine (see p. 310). Thus gelatine may be formed in the animal organism from the decomposition of protein, in the manner pointed out when speaking of the action of alkalies on protein (p. 309). That process may be modified by the weak alkaline character of the serum of the blood, but in the main it must be the same as we then mentioned. By the oxidizing influence of the oxygen carried into the blood through the lungs, either no formic acid is produced in the blood as is there represented (formula, page 309), or it is immediately changed into carbonic acid. Thus the products into which protein is decomposed by the alkali in the blood, are carbonic acid, ammonia, protid, erythroprotid, and leucin. Along with 2 equivalents of ammonia, there are produced—

Protid, $C^{13}\ H^9\ N\ O^4$

Erythroprotid, $C^{13}\ H^8\ N\ O^5$

If to the elements of each of these, one of the equivalents of ammonia is added, the products are,

$C^{13}\ H^{12}\ N^2\ O^4$

And $C^{13}\ H^{11}\ N^2\ O^5$

From this it appears that by the continual action of oxygen carried into the blood by the lungs, the gelatinous tissue may be formed from protid by the addition of 3 of oxygen (O^3), and from erythroprotid by the addition of 1 of oxygen (O). Thus

$C^{13}\ H^{12}\ N^2\ O^4$ with O^3

Gives $C^{13}\ H^{10}\ N^2\ O^5 + 2\ HO$

And

$C^{13}\ H^{11}\ N^2\ O^5$ with O

Gives $C^{13}\ H^{10}\ N^2\ O^5 + HO$

—that is, by the absorption of oxygen into the lungs, gelatine (C^{13} H^{10} N^2 O^5) and water (HO) are produced from protid and erythroprotid, after being combined with the ammonia which is disengaged from protein by the alkali in the blood.

According to this formula, therefore, the substances which are produced from the decomposition of the protein in blood, merely through the action of the alkali in the serum, and the oxidizing influence of the atmosphere, are—carbonic acid, water, gelatinous tissue, and leucin. The carbonic acid passes off through the lungs, the water through both the lungs and the kidneys. The gelatine requires only form to become cellular tissue.

Leucin, however, has not yet been found in the body. Every attempt to explain the formation of gelatine must be in vain, until either leucin or the products of its decomposition are discovered in the body.

I have thought it necessary, however, to give these explanations, with the view of drawing attention to the complex character of protein and gelatine, and to the great improbability that protein should be transformed into gelatine merely by taking or losing oxygen, water, and ammonia; and further, to the probability that the alkali in the serum has a most important influence on the transformation of protein, and that the formation of protid and erythroprotid from protein and alkalies, seems to pave the way for a reasonable explanation of the mode in which the gelatinous tissues are produced. Our knowledge of all this, however, is very slight as yet, because our knowledge of the so-called extractive matters in the serum is limited.

We are likewise but imperfectly acquainted with the products of decomposition of the gelatinous tissues in the body, because we do not know enough of the substances produced by the decomposition of gelatine. By the influence of oxidation prussic acid is formed;* by the action of alkalies, gelatine sugar, leucin, and extractive matters are produced, while ammonia is disengaged, and an alkaline carbonate formed.†

* Persoz, in Annal. der Chemie und Pharmacie, Decemb., 1842. It is, however, denied by Sullivan. Ibid.

† These experiments are mentioned in Bulletin, 1838, p. 145.

Finally, gelatine, when boiled in dilute sulphuric acid, produces extractive matters with either gelatine sugar or leucin.* Since leucin is also produced from albumen, when decomposed by potash,† we perceive an intimate connection between the protein compounds and animal gelatinous substances. They both form similar combinations in the blood, and can thus give the same products of decomposition under certain conditions.

When treating of sugar (p. 231), we mentioned the substances which are produced from the decomposition of gelatine sugar. If the cellular tissue, formed from protein in the way above stated, can be dissolved again, it must exist in a state of solution, that is, as gelatine, in the blood, and if decomposed there by the alkali of the blood, it produces (besides unknown extractive matters) gelatine sugar, which can be decomposed into urea and sugar. The former of these is rejected through the kidneys, while the latter may be employed in the body for other purposes still unknown.

Doubts have recently been started as to whether gelatine is nourishing for man; and, following in the wake of the French Academy, many persons even consider gelatine as entirely useless as food.‡ Such persons only as are under the influence of prejudice, (making their experiments with dogs—animals which, according to the account of the Gelatine Committee, prefer to starve in the midst of gelatine, rather than touch it)—such persons only as deny the results of innumerable observations, will deny to gelatine its place among useful nutritive substances. Every one who has practised medicine for many years, as I have done, and who has had opportunities of seeing innumerable convalescents or enervated persons recover their strength, by the use of arrow-root and jelly of hartshorn, must regret that any one has thought experiments capable of leading to a right decision, in cases

* Bulletin, 1838, p. 145.

† Ibid, p. 145

‡ See, for instance, Verslag an Z. E. den Minister van Binnenlandsche Zaken, in het Instituut, 1843, N. 2, p. 97. (Account to His Exc. the Minister of the Interior, in the Royal Institution, 1843, N. 2, p. 97.)

where experiments are inadmissible and superfluous, observations alone being likely to guide us to the truth.

This is not the place to explain how gelatine acts in nourishing the body; we rather reserve the subject till we treat of animal food. I have thought it necessary, however, before closing this short account of gelatine, to express my opinion of the experiments hitherto made, by which pure gelatine is rejected as food; namely, that those experiments have taught me nothing, but how experiments ought *not* to be made.

Besides the gelatine which is obtained from cellular tissue and serous membranes, there is another kind which has many of its properties, but is different in composition. It was first described by J. Müller, under the name of *chondrin*. It is obtained from the cornea, and the permanent cartilages,—for instance, those of the nose, the ears, the arteria aspera,—and from the cartilages of the joints and ribs, by boiling them in water. From the existence of this second kind of gelatine, therefore, we must infer that of another kind of tissue. The composition of this tissue just as much resembles chondrin, as the ligamentary tissue does the gelatine prepared from it. By analysing, for instance, the cartilage of the ribs, nearly the same composition is obtained as from chondrin, prepared by boiling this cartilage. Thus it would appear that these tissues consist almost entirely of chondrin, as isinglass does of gelatine. (See *Cartilaginous Tissues.*) Its composition is:—

$$10\,(C^{32}\,H^{26}\,N^{4}\,O^{14}) + S.$$ *

The substance which produces chondrin is formed under

* Bulletin, 1838, p. 77.

	Found.	Atoms.	Calculated.
C	49.96	320	49.93
H	6.63	260	6.61
N	14.44	40	14.47
O	28.59	140	28.58
S	0.38	1	0.41

We have determined the atomic weight of chondrin, by combining it with sulphate of iron, and that of chondrin freed from sulphur, by uniting it with chlorine. The latter has been analysed by Schröder (Scheik. Onderz. D. I. p. 270)—

other circumstances than that which produces gelatine. We know this chiefly from the fact, that the rib-cartilage of old animals in process of ossification gives gelatine and not chondrin upon being boiled. At that period, therefore, this cartilaginous tissue has undergone an entire change, and has been converted into the tissues of the bones. The tender bones of the fœtus, on the other hand, give chondrin, instead of gelatine, before ossification has commenced; after that time, they give gelatine.*

Chondrin, when placed in contact with chlorine, forms a chlorine-compound—one which does not contain chlorous acid.

	Found.	Atoms.	Calculated.
C	46.11	32	45.96
H	6.09	26	6.09
N	13.71	4	13.30
O	26.88	14	26.31
Cl	7.21	1	8.32

Schröder has also repeated my former analyses of chondrin, different results having been obtained by Scheerer and Vogel. Scheerer (Annal. der Pharmacie, Bd. xl., S. 49) has analysed the *whole* of rib-cartilage and of the cornea, and found:—

	Rib-cartilage.		Cornea.	
C	50.90	49.19	49.52	50.03
H	6.96		7.10	
N	14.91		14.40	
O	27.23		28.98	

Scheerer's results and mine approximate, the hydrogen excepted, which, however, is a very essential point. Schröder found exactly the same proportions as I did:—

C	49.93	32	49.93
H	6.61	26	6.61

Scheerer's experiments, however, may serve to show, that the difference between rib-cartilage and chondrin is just as small as that between the air-bladders of fishes and isinglass. Vogel's results from the analysis of chondrin (Journal de Pharmacie, Août, 1841, p. 497) are wrong as respects the proportion of carbon:—

C	48.97
H	6.53
N	14.55
O	29.63
S	0.32

* Müller, in Poggend. Annalen, Bd. xxxviii. p 316.

Its composition is represented by the formula $C^{32}H^{26}N^4O^{14}Cl$, as has been found by Schröder.

These are the only gelatinous substances in the animal body with which we are as yet acquainted. The Pyïne obtained by Güterbock from the matter of tubercles, and from that of granulation, from pseudo-membranes, the skin of the fœtus, the condyles, &c., is nothing but tri-oxide of protein. Finally, gelatine from elastic tissues, has properties which are intermediate between those of chondrin, tri-oxide of protein, and common gelatine. It seems to be a mixture of these.

The origin of the ligamentary tissue is involved as yet in almost perfect darkness. In attempting to trace its origin, great assistance is derived from the observation, that the bones of the fœtus at first contain chondrin; that, as soon as ossification has begun, they are changed into gelatinous tissue; and that ossifying cartilage by ebullition no longer yields chondrin, but gelatine. This, it is true, does not prove that every gelatinous substance has previously been chondrin tissue, and that, therefore, the skin, serous membranes, &c., previous to their existence in such a state as to produce gelatine by ebullition, should yield chondrin. The possibility of this fact, however, is undeniable, and it deserves, therefore, to be investigated. It has been ascertained by experiment, that both the chondrin-tissue of the bones, and that of rib-cartilage, can be converted into gelatinous tissue.

It follows, then, that in those organs, chondrin is the primary, gelatine the secondary product. We have, therefore, to ascertain how chondrin is changed into gelatine, and how chondrin is produced.

As to the latter point, we observe two kinds of chondrin-tissue in the body:—the one in the fœtus is converted into gelatine-tissue before birth (in the bones); the other preserves its existence for a number of years, and undergoes this change in very old age only. This is a remarkable difference, and cannot be explained chemically; it must depend on the form, or upon what we are accustomed to call the organization.

It is remarkable, besides, that the real gelatinous tissues do not all secrete the earthy bone salts; this property being possessed only by the gelatinous tissue of the bones, and the real cartilaginous tissue (in old age). The skin and the serous membranes, which are also real gelatinous tissues, are destitute of that property. Neither can a chemical explanation be given of this difference, which must therefore be traced to the form or the nature of the tissue.*

The formation of chondrin in young unossified bones, we can attribute only to a protein-compound. For in the chicken, of which the tender bones contain chondrin, the principal constituents to be found are only albumen, oxide of protein, and fats; the fats have no share in the formation of chondrin. We may assume, that in the complete organism, chondrin is formed and sustained by means of the same materials as in young animals.

If we attend merely to the composition in the hundred parts, chondrin would appear to be a bi-hydrate of the tri-oxide of protein. For the results of the analysis can nearly be represented by $C^{40} H^{31} N^5 O^{15} + 2 H O$.† But this would be to twist the results of the analyses to our own purposes; and, besides, the proportion of carbon in the combination of chondrin with chlorine (p. 329) is not at all in accordance with this assumption. We are, therefore, not entitled to regard chondrin as identical with tri-oxide of protein.

As to the formation of gelatinous tissue from chondrin, which undoubtedly takes place, it cannot be very different from the formation of the same tissue out of protein-compounds. For the skin and the serous membranes are produced from the latter directly, not after a preceding formation of chondrin, as in the true cartilaginous tissue, and in that of the bones. This, however, cannot be explained by chemistry. Of gelatine itself, too little is yet known, nor are we yet acquainted with any other connection between gelatine and

* See *Tissues*.

† Compare the experimental results mentioned in the note at pp. 312 and

protein, than what we have shown to exist in leucin and gelatine-sugar (p. 326). Of this process we cannot form any determinate idea, until new experiments have been successfully performed.

The Colouring Matter of Blood.

The blood of red-blooded animals contains a very remarkable substance, which probably plays an important part in the body, but of which we do not yet know the functions. I mean, the red colouring matter of the blood. From its absence in some classes of animals, we may conclude, that it is not indispensable to animal life. It may be true, that the structure of white blooded animals differs from that of the red blooded; but there is so much similarity among the functions of both, that this red matter cannot be considered as indispensable to animals. It is said to perform an important service, wherever the organs of respiration are in a more developed state. Since it is not present in plants, animals cannot get it from that source; it must therefore be produced from vegetable food in the body itself in the case of such red blooded animals as live only on vegetable food. We are yet entirely unacquainted with the mode in which it is produced, and hence many vital functions are still involved in obscurity.

This colouring matter is contained in vesicles, of which an innumerable multitude exist in the blood. They are called blood-globules. The walls of these vesicles retain this colouring matter; but a small quantity of it occasionally passes through them. Although, therefore, the greater quantity of it is enclosed in these globules, and within them is diffused through a liquid, another part is found without them, in the serum.

It has been universally assumed, that the two kinds of red blood which exist in animals, contain the colouring matter in two chemically different conditions. In arterial blood it should possess an excess of oxygen; in venous blood an excess either of carbon or of carbonic acid. The grounds upon which these suppositions were made to rest, are:—that arte-

rial blood is of a bright red, and venous blood of a dark red colour; that the latter becomes bright red when mixed with oxygen; that in the lungs, where venous blood is changed into arterial blood, oxygen is taken up and carbonic acid disengaged, and that, therefore, a real chemical difference must exist between the colouring matter of arterial, and that of venous blood.

It is not necessary, however, that either the bright red colour should be owing to oxygen, or the dark to carbon or carbonic acid; because the same change of colour can be produced by other substances besides oxygen. Among those substances are solutions of entirely neutral salts, which do not disengage oxygen; for instance, saltpetre, sulphate of soda, and many others. When venous blood is either received in, or is mixed with these solutions, it becomes as bright red, as when it is exposed to the influence of oxygen. It is by no means necessary, therefore, to assume that the change of colour of the blood in the lungs, is due to a change in the chemical composition of the colouring matter, dependent either on a higher or lower degree of oxidation, since both saline solutions and oxygen have the same effect.

The colouring matter may be extracted from clotted blood by alcohol mixed with a small quantity either of sulphuric acid, or of ammonia,—or better still, by pouring blood into a solution of sulphate of soda, allowing it to settle, and then treating the layer of blood-globules at the bottom with alcohol and sulphuric acid.

The colouring matter of the blood (hæmatin) can combine with acids and alkalies, like protein. By this property the incalculable series of combinations in the animal body is greatly increased. It is almost insoluble in water, alcohol, and ether, and in acids and alkalies; but it is soluble in alcohol containing either an acid or an alkali. When separated in the above manner, and freed from sulpho-proteic acid, chemists call it coagulated colouring matter. It is, however, incapable of coagulation. The opposite idea has originated in the property formerly found to be possessed by colouring matter containing albumen, – the latter substance being the only

cause of the coagulation. It can hardly be called coagulated, since it is completely soluble in alcohol mixed either with sulphuric acid or with ammonia. The solution, even when diluted, has a dark colour, and possesses all the properties of the colouring matter of venous blood, notwithstanding it has been obtained in contact with the air, and therefore placed in the condition of arterial hæmatin.

It is not likely that the mode of preparation can have made any alteration on the substance. The only alteration which could possibly take place, would be a change from the venous into the arterial character.

Its composition is always the same, when prepared in the way above described from the blood of different animals, whether the blood be venous or arterial, namely:—

$$C^{44}\,H^{22}\,N^{3}\,O^{6}\,Fe.^{*}$$

Some chemists have found that the proportion of iron is variable; but the cause of such differences is to be looked for in the experiments themselves. The proportion of iron is invariable, when the substance is properly prepared. The iron is chemically combined with the hæmatin, and thus constitutes one of its elements. It can, however, be separated

* Bulletin, 1839, p. 74.

	I.	II.	III.	IV.	V.
C	66.49	65.91	66.20	65.73	65.90
H	5.30	5.27	5.44	5.28	5.27
N	10.54		10.46	10·57	10.61
O	11.01		11.15	11.97	
Fe	6.66	6.58	6.75	6.45	

No. I. was prepared from arterial ox-blood,
II. ... from similar blood,
III. ... from similar blood,
IV. ... from venous ox-blood,
V. ... from mixed sheep-blood.

	Atoms.	Calculated.
C	44	65.84
H	22	5.37
N	3	10.40
O	6	11.75
Fe	1	6.64

from it. If, for instance, hæmatin be diffused through water and exposed to the action of chlorine, the iron disappears, being dissolved in the hydrochloric acid produced, and 6 equivalents of chlorous acid (6 Cl O^3) are substituted for one of iron (Fe). The substance has now become white, and its composition is—

$$C^{44}\ H^{22}\ N^3\ O^6 + 6\ (Cl\ O^3).*$$

The iron can be separated in another way also, so as to leave a red colouring matter behind. For this purpose dried blood must be mixed with strong sulphuric acid, the mixture left together for some time, and water then added. Hydrogen gas is disengaged, and sulphate of iron remains dissolved in the water, and can be detected by the usual reagents. After the remaining blood is thoroughly washed and extracted with alcohol and a little sulphuric acid, red hæmatin, free from iron, is obtained in combination with sulpho-proteic acid. Van Goudoever has found this compound, though prepared in different ways, to be of a constant composition, which may be represented by the following formula:—

$$C^{84}\ H^{57}\ N^8\ O^{22}\ SO^3 =$$
$$C^{44}\ H^{22}\ N^3\ O^6 + C^{40}\ H^{31}\ N^5\ O^{12}\ SO^3 + 4\ Aq.\dagger$$

When hæmatin, prepared in the manner first described—that is, containing iron, and free from protein and sulphuric acid—is mixed with strong sulphuric acid, and after being so

* Bulletin, 1839, p. 411.

	Found.	Atoms.	Calculated.
C	37.34	44	36.46
H	3.01	22	2.98
N	5.89	3	5.76
O	24.34	24	26.62
Cl	29.42	6	28.78

† Scheikund. Onderzoek., D. II., p. 137.

	Found.	Atoms.	Calculated.
C	56.963	84	57.08
H	6.799	57	6.32
N	12.675	8	12.59
O	19.143	22	19.56
SO^3	4.420	1	4.45

left for some days, is diluted with water, hydrogen gas is disengaged, and the solution contains sulphate of iron. In this manner all the iron can be dissolved, and the organic elements—

$$C^{44}\ H^{22}\ N^{3}\ O^{6}$$

can be obtained in mutual combination.*

The iron, therefore, is a constituent of hæmatin, which can be separated from it; but at the same time, the nature of the colouring matter is thereby entirely changed.

It has been assumed that this iron is very loosely combined with the colouring matter, so that it can be oxidized and de-oxidized in respiration,—the real organic constituents not being comprehended in this action. As, however, the quantity of hæmatin existing in blood is very far from sufficient to combine with all the oxygen taken up in respiration, it is undeniable that it is not the iron which takes and carries throughout the body the quantity of oxygen which is converted into carbonic acid by respiration.

Moreover, the iron is very intimately combined with the four organic elements of the hæmatin; so much so that, if duly prepared, it may be digested with diluted hydrochloric or sulphuric acid for many days, without the least diminution of the quantity of iron. From hæmatin, treated in this manner, I obtained, after combustion, 9.49 per cent. of oxide of iron, which is the constant quantity always left after combustion by properly prepared hæmatin.

The idea, therefore, that the iron can be separated from blood without producing a complete change in the nature of the colouring matter, may justly be called inaccurate.

Liebig, who is of a different opinion, rests it on the observation, that iron can be dissolved from dried blood by di-

* Scheikund. Onderzoek., D. II. p. 151.

	Found.	Atoms.	Calculated.
C	70.18	44	70.49
H	5.92	22	5.76
N		3	11.16
O		6	12.59

luted acids. But other constituents of the blood besides the hæmatin contain iron. When pure serum is burned, it leaves an ash which, like that of the albumen from eggs, contains iron. It is this oxide of iron, and not that of the hæmatin, as Liebig imagines,* which can be extracted by diluted acids from dried blood.

We must assume the iron to exist in pure hæmatin in the condition in which it is present in arterial blood. There it may exist either in the state of highest oxidation, that is, $Fe^2 O^3$ (peroxide of iron), (for nobody will think of meeting here the ferric acid of Fremy,) or as an organic constituent combined with carbon, hydrogen, nitrogen, and oxygen—in the state of metallic iron, that is, and not of oxide of iron.

If this iron were as easily changed from carbonate of protoxide of iron into peroxide (when venous blood becomes arterial in the lungs), and *vice versa* (by the opposite process in the capillary system) as Liebig assumes, then it should be possible to extract all the iron from hæmatin by a weak acid. But this is by no means the case; on the contrary, as I have already said, the quantity of iron cannot be diminished, unless the iron and the colouring matter at the same time be attacked by a strong acid.

An alternate change of the iron into carbonate of protoxide, and into peroxide by respiration, must therefore be regarded as impossible.

There is another reason, besides, which unquestionably proves that the iron does not exist in the state of peroxide in the colouring matter prepared in contact with the air, that is, such as it is present in arterial blood. For in the first place, this colouring matter can be freed from iron by strong sulphuric acid with disengagement of hydrogen, which could not happen if peroxide of iron ($Fe^2 O^3$) were present in it; in the second place, after separation of the iron, $C^{44} H^{22} N^3 O^6 Fe$ leave $C^{44} H^{22} N^3 O^6$, while the remaining substance should contain $O^{4\frac{1}{2}}$, since if $Fe^2 O^3$ were really

* Animal Chemistry, Dutch edition, p. 235.

present, it must be in combination with a substance represented by 2 ($C^{44} H^{22} N^3 O^{4\frac{1}{2}}$).*

For these reasons, I think it unquestionable that hæmatin does not contain the peroxide of iron, ($Fe^2 O^3$) but that the iron exists in it in the same state as iodine does in sponge, sulphur in cystin; or, to express our idea more clearly, as arsenic does in cacodyl, as represented in the following formulæ:—

$C^4 H^6 As$	Cacodyl
$C^4 H^6 As + O$	Alcarsin
$C^4 H^6 As + O^3 + Aq.$	Alcargen

Some light may be thrown on the function of the colouring matter in the blood, if it really takes up oxygen, by applying to it the principle of the above formulæ, by which Berzelius has represented the substances discovered by Bunsen.

If, however, we bear in mind what has just been remarked as to the change of the red colour in venous blood by salts, which cannot give off any oxygen, then we shall perceive that we have but little ground for holding that a chemical change of the hæmatin in the lungs is likely to happen.

Several old experiments, repeatedly published, and some more recent ones by Scheerer, render it still more improbable, that the hæmatin is oxidized in the lungs.†

When recent ox-blood of a bright red colour is mixed with 2 or 3 times its bulk of water, it becomes dark red. When oxygen is passed through the solution, it retains that dark colour. If, however, a little milk, oil, finely powdered chalk or gypsum, is mixed with the blood and water, the colour becomes again bright red.

These experiments seem to prove that the bright red colour of blood depends upon other causes than oxidation;

* It is exceedingly difficult to free hæmatin from iron by means of the first hydrate of sulphuric acid. The separation can only be effected by treating it repeatedly with strong sulphuric acid, soaking it for many days, mixing it with water, and washing it for a long time.

† Zeitschrift für rationelle Medicin, Bd. i. S. 288. The greater part of the experiments mentioned by Scheerer, are to be found in Müller, Physiologie, D. I. p. 310.; Simon, Medic. Chemie, D. II. p. 101.

and therefore the dark red colour upon other causes than the presence either of carbon or of carbonic acid. From a glance at these experiments, we learn, that the bright red colour is connected with the presence of white particles suspended in the liquid. This conclusion is still further confirmed by the result of microscopical investigation.

The colouring matter exists chiefly in the little disks of the blood. This and the following observations were made by Hewson as early as 1785.* Those disks are bi-concave when the blood is of a bright red colour; and they then reflect a great deal of light, and act as powdered chalk, milk, &c. When the blood has a dark colour, the blood-corpuscles are either bi-convex, or their covering is so thin that they transmit all the light; or they are wholly dissolved, while the colouring matter is diffused through the water. This takes place when bright red blood is mixed with water. The corpuscles then swelling, become bi-convex and spherical, while the envelope becomes thinner, and finally disappears, the colouring matter passing through it, and being diffused in the water.

If the contact of these blood-corpuscles with the water be of shorter duration, and if, after the colour has become a little darker, a saturated solution of any neutral salt be added, then the same bodies reappear distinctly, and become bi-concave again. They contract, or rather, the water penetrating through the film, is mixed by exosmose with the solution, and so the colour becomes bright red again. It is clear, that if the addition of the saline solution has been delayed too long, the red colour cannot be restored, because then the envelopes of the corpuscles are too much extended, or even dissolved, and have disappeared. The red colour can then be restored by chalk, &c.; while if, by passing oxygen through the dark red liquid, the bright red colour does not re-appear, then none of the blood-globules are longer visible in the liquid.

When a piece of the clot is triturated with a saline solution, a bright red liquid is obtained, from which, if kept in a cylindrical glass, a bright red layer of blood-globules falls to

* See Schultz, über die Hewsonsche Untersuchungen der Blutbläschen, Leipzig, 1835

the bottom, above which is a pale red liquid containing few or none of these globules.

When the upper layer is decanted, and water is added to the inferior bright red layer, the globules of blood disappear, and the colour becomes dark red.

When blood is allowed to stand for some days in a saline solution, the bright red is changed into a dark red. Much carbonate of ammonia is produced, and the corpuscles are entirely changed, flaccid, and decomposed.

When carbonic acid is passed through recent bright red blood, containing bi-concave disks, the latter become bi-convex, and the blood turns dark red.

These experiments, by Scheerer and others, prove that during respiration no oxidation is required to change the colour of blood from dark into bright red. To these experiments I will add some others made by E. T. W. von Baumhauer, of which I have seen the results.

When clotted ox-blood is cut into pieces, and then exposed to the air, it turns bright red at all the points which are in contact with the air. If these pieces are then plunged into the alkaline serum, they become dark again: if again exposed to the air, they reassume the bright red colour, but under water they become dark again.

When dark-coloured clotted ox-blood is put into a solution of iodide of potassium, or of sulphate of soda, it becomes very bright red. The same happens, though the colour is less bright, when it is put into a solution of saltpetre, sulphate of potash, or common salt. The colour becomes darker again, if the substance is either put under water or is subjected to the action of an acid.

Bright red pieces, laid in a very weak solution either of potash or ammonia, soon become black. They swell and become gelatinous. The same effect is produced, though more slowly, by watery solutions of soda, lime, and baryta.

Such pieces blacken also in carbonic acid, in water, very diluted solutions of tartaric, oxalic, sulphuric, phosphoric, hydrochloric, acetic, nitric, or boracic acids. The order in which we have enumerated these acids, indicates their relative

power of blackening. The liquid at the same time becomes dark red.

Globulin is coagulated by the above saline solutions. By acids it is first rendered gelatinous, and then dissolved; alkalies have the same effect. This much may be stated regarding globulin, as agreeing with the properties which fibrin is known to possess.

We shall now endeavour to explain the cause of the change of colour which blood undergoes in the lungs, assuming that the colouring matter is not changed by this process.

The hæmatin is almost entirely enclosed in thin films, the corpuscles of the blood being cells, each of which in general possesses a kernel. The membranes of these cells consist of a protein-compound, which is not albumen, but is either the substance which forms fibrin when blood coagulates, and which, on the dissolution of the membrane, is diffused in the serum,—or it is a peculiar protein-compound termed globulin. For our present purpose, it does not matter which of the two we assume. The substance from which, in coagulated blood, fibrin is formed, exists in the liquid blood in a state of solution.

Now, it is a characteristic of protein-compounds—especially of the substance which produces fibrin—to form two oxides, $C^{40}\,H^{31}\,N^{5}\,O^{14}$, and $C^{40}\,H^{31}\,N^{5}\,O^{15}$, when in contact with the oxygen of the air. A combination of this kind is found in the inflammatory crust.* When that protein-compound is oxidized, and these two oxides are produced, it assumes a character of plasticity, *i. e.*, has a tendency to become solid, adheres to solid substances, and is deposited as a thin layer round the cellular membrane of the little blood corpuscles.

Thus, when a respiration is performed, the exterior layer of this cellular membrane must consist of a substance similar to that which constitutes the inflammatory crust; it must be less transparent and white. So it is in arterial blood. In the capillary system, this exterior white layer of the membrane is employed in the change of the substance of the body, and is thereby consumed entirely. The remainder having lost

* See above, p. 311 and 312.

the white layer, has become transparent again, and represents red hæmatin in its normal state. That dark colouring substance in the globules of arterial blood, shining through a white layer, must necessarily appear bright red, as is the case with dark red blood when poured into a vessel of milky glass—as has been remarked by Scheerer.†

There is another observation, which may be of use to our present purpose, namely, that the bright red bodies are bi-concave, the dark red, bi-convex. It is well known that the inflammatory crust is very apt to curl up at the edges, and to become concave. If the blood-corpuscles are really surrounded with an envelope of oxide of protein in the lungs, the form assumed by the two laminæ, on both sides of the little flat body, must resemble that of the inflammatory crust. This at the same time explains the bi-concavity of the corpuscles. When an inflammatory crust is formed, it has such a strong tendency to become bi-concave, that the middle part of the crust is entirely depressed. In as far, therefore, as the reflection of light is to be taken into view, in accounting for the bright red colour of the corpuscles, and the transmission of light in accounting for their dark red colour, the fact just stated in regard to their form, is applicable also to the phenomenon now under consideration.

In the last place, it is justly observed by Scheerer, that the corpuscles of venous blood have the same form as those of arterial blood; but this by no means shows that there is no difference between them; for the thin layer of venous blood, as soon as it is put upon the object-glass of the microscope, is thoroughly exposed to the air, and is thus quickly changed into arterial blood.

I do not agree with Scheerer, in regarding the whole phenomenon of the reddening of venous blood in the lungs as a complex effect resulting from the loss of carbonic acid and water, the absorption of oxygen and the admixture of the

† We perceive the great influence effected by this transmission through animal tissues on the colour of hæmatin, in the fine blue colour assumed by the brown, venous blood, when shining through the veins, skin, &c.

milk-white chyle from the thoracic duct; but I consider it merely as the result of the production of oxy-protein.

The dark colour of the blood in the vena portalis,—to account for which recourse was formerly had to carbon, as if blood contained charcoal—may be deduced, in the way above described, from the nature of the cellular membrane of the blood-corpuscles. The darker colour of the blood in the vena portalis is attributable to the existence of a somewhat larger quantity of carbonic acid (or of alkali), because the membrane of the small bodies becomes more gelatinous and transparent, in consequence of such an increase.

It is known, that even fibrin and albumen are first reduced to a jelly, before they are dissolved by diluted acids.* When, therefore, carbonic acid is passed through bright red blood-corpuscles, diffused in water, the white envelope must become transparent and gelatinous; and the natural dark red colour of the hæmatin must appear.

Though this change, effected by an artificial process, seems to explain the darkening of the colour of the blood in the capillary system, it has no resemblance whatever to the process going on in the capillary system, where the carbonic acid, the moment it is set free, combines with the alkali in the blood, and does not make the serum acid, as occurs when carbonic acid is passed through blood in water. Thus the carbonic acid cannot be the agent by which the membrane of the corpuscles of venous blood is made transparent; this acid, therefore, cannot be reckoned among the causes which produce the dark colour of venous blood. For the same reason, the shape of the blood-corpuscles in venous blood must differ from that in blood mixed with water, through which an excess of carbonic acid has been passed. Venous blood must contain a thinner membrane, a more globular cell; in blood mixed with water, artificially impregnated with an excess of carbonic acid, a gelatinous transparent cellular membrane must be found.

Finally, the reddening of dark coloured blood by concen-

* Scheikund. Onderz. Deel I. p. 576.

trated saline solutions ought undoubtedly to be ascribed to a kind of coagulation, which the cellular membrane of the blood-corpuscles undergoes. This phenomenon has no relation to the reddening by oxygen, but agrees with it so far, that the membranes become white in both cases. In the one case, however, they become white by oxidation, and probably by the condensation of a new layer on the surface; in the other case, by the contraction of the membrane itself. The property of globulin, to become contracted by sulphate of soda, saltpetre, &c., is of much importance. It is one of the most powerful proofs, that globulin has a distinct existence, and does not take a large share in the change of the materials of the body.

I have shown elsewhere* that oxygen is taken up in the lungs by the protein-compounds of the blood. Hæmatin probably performs no part whatever in respiration; for no change is effected on its colour either by oxygen, carbonic acid, or protoxide of nitrogen, and only a very slight one by sulphurous and hydro-sulphuric acids. This appears from experiments, which I made with hæmatin in a separate state†—experiments which suggested my doubts with respect to the oxidation of hæmatin in the lungs.‡

It is not so easy to be explained where hæmatin is formed, and what becomes of it. It is unquestionably a secretion from the vesicle of the blood-corpuscles, and as we may assume with great probability that those corpuscles originate from globules of lymph,§ hæmatin must be formed within the range of the circulation itself from one of the constituents of the blood.

In regard to its reproduction, waste, and restoration, we may consider these to be as certain, as in the case of all the other organic constituents of the body. The purpose of its

* Scheikund. Onderz. Deel I., p. 550.

† Bulletin, 1839, p. 79.

‡ Bulletin, 1839, p. 82.

§ Julius Vogel asserts that he has seen a formation of corpuscles of the blood in Fungus medullaris. Icones Histologiæ Pathologicæ, Tab. 5. I consider this not likely.

existence, however, is still uncertain, since the only ground for presuming that it was of use in respiration has been set aside. We are therefore ignorant also of the transformations which it undergoes in the body. It is likely, however, that the products of its decomposition are to be found in the bile; and perhaps the bilifulvin may originate from hæmatin, which has served its purpose in the body.

It is not likely that hæmatin undergoes a rapid re-production. Being entirely enclosed in vesicles, it does not separate until the walls of those vesicles are dissolved. This view is confirmed by the apparently high degree of stability which is possessed by the blood-corpuscles.

We have lastly to answer the question, whether hæmatin is present in the blood globules in a state of chemical combination, or in an entirely free state?

We have discovered a combination of sulpho-proteic acid with hæmatin free from iron—a constant combination extracted from blood by sulphuric acid. It may be really present therefore in those corpuscles, in the state of a chemical combination with a protein compound. This is still more confirmed by the obstinacy with which the colouring matter is retained by red serum when coagulated by heat.

It is, however, not known what kind of combination it forms in the corpuscles of the blood, nor what its physiological relations are.

What I have stated as to the colouring matter of the blood has been mentioned only for the purpose of modifying the prevailing ideas as to its functions. It is not, I think, one of those substances which perform a principal part in the organism, and it ought not, properly speaking, to have been treated of here. It is generally considered of importance in a chemico-physiological point of view, an opinion in which I do not concur.

The substances now enumerated, as far as we know at present, and we may state this with great probability, constitute the chief component parts of plants and animals. Both kingdoms, however, contain an almost incalculable number of other

substances in addition to these. In plants, there are acids of different characters, bases, colouring matters, bitter substances without nitrogen, volatile oils, and resins; but all these are not to be classed among the substances which are common to all plants. We shall, therefore, return to these, when treating of the different functions of plants,—those functions by which they are produced. A great many of the animal substances also act an important part in the functions of the several organs. To these belong especially the secretions; they are products formed from the decomposition of the general constituents of the animal body, and are therefore worthy of our particular attention. We shall treat of these when we come to consider the functions themselves.

CHAPTER VII.

CONSTITUENTS OF THE ORGANISED KINGDOM HAVING PECULIAR FORMS.

A. Elementary Forms of Organised Parts.

We have in the former chapters considered the general materials that constitute the organic kingdom. Although we have repeatedly drawn attention to the peculiar form which they assume, yet this form is worthy of a more particular consideration. It is especially the form assumed by the substances, of which the smallest constituent parts of the organs are composed, that requires investigation. These substances are either simple organic bodies, or combinations of several of these bodies together.

The characteristic property of organised parts is, the performance of a certain function. By this property they are, as it were, directly opposed to the unorganised parts: for as the former are continually in a state of transformation, a state which is necessarily connected with the performance of a function—so it is inseparable from the existence of the latter, that they remain permanently in the same condition, provided that condition be not changed by external causes.

We need not explain what is meant by the term "function." In a general sense, it is the manifestation of an action externally, whether that action be the production of a new substance or a simple motion. These manifestations, whatever may be their nature, are not only peculiar to living bodies, but they are essential to every organised molecule

which contributes to the production of a living body. Such a body is able to present itself as a substantive whole, and to perform functions, which must be regarded as the sum of the functions of the molecules. (P. 83.)

When we survey the constituent materials of the organic kingdom, and perceive how small their number is, how few the means are through which an incalculable variety is attained, the conclusion seems obvious, that it is not difference of material, numerous as its chemical peculiarities may be, that can produce such a variety. Vegetable substances, apparently identical, not only present themselves under entirely different forms, but they also produce,—in the poppy, for instance,—certain bodies which are entirely different from those produced either in the aconite or in the oak-tree ;—nay, in different organs of the same plant, they give rise to entirely different products, and perform entirely different functions. The same observation applies to the chief constituent parts of the animal kingdom.

But although the observation of material identity united with dynamic difference in a certain substance seems to impel us to the conclusion, that a function cannot be a manifestation of force by a chemical substance *as such ;* it is, however, conceivable, that all the primary causes of the actions performed by any substance, may, in the end, be brought home to the peculiarities of matter itself.

In the most general sense, a function is a manifestation of a certain phenomenon. If it be true that this cannot be effected by matter by means of the forces which are either stored up or capable of being awakened in it, unless this matter has assumed certain forms, then this form is a condition as indispensable to the performance of the function, as is the nature of the substance which takes that form. If any vegetable or animal tissue be destroyed by a mechanical force,—if a single membrane of a cell be injured by a pointed body,—this tissue or this membrane will immediately cease to perform its normal functions and to maintain itself.

We have learned, by a successful observation of nature, that in the organic kingdom the form of an organised part

is of as much importance as its material to the performance of its function. We find that minute differences of material give rise to difference in form, and that minute differences in form are followed by a difference in material. Form and matter, matter and form, are so intimately united in the actions of organic nature, that it would be scarcely possible to determine which is the primary and which the secondary condition. Hence the importance of microscopical investigations into the structure of large organs, even in their most trifling peculiarities;—in other words, of studying the forms, under which substances, apparently identical in a chemical sense, present themselves, enabled as they are by difference in form, to perform entirely different functions.

If, however, we enter somewhat more deeply into the origin of differences in form among apparently identical chemical substances, the undeniable maxim, "that where causes are the same, effects must be the same also," compels us as it were to conclude, that the same substance can assume only one form; that, therefore, difference of form must be accompanied by difference of matter. But those differences can be, and really are, of a very different nature. The most trifling heterogeneous immixture present in any universal constituent of the whole vegetable and animal kingdoms,—in the cellular matter, for example,—makes it essentially different, and accounts for differences in form which arise from that variation alone. Those differences would otherwise indicate such deviations from what we observe in nature, that we should be inclined to consider them as unnatural.

Of such differences there exists an immense number. Many of the so-called inorganic constituents of the organized bodies are, no doubt, the cause of their production; for when we find a small difference in the proportion of lime, magnesia, or any other base in the same cellular matter, of which the various cellular systems of a plant are composed, then the materials of which one system is composed are no longer identical with those of which the others are built up, provided the lime, magnesia, &c., are chemically combined with the cellular matter. It appears to be certain that such minute quantities

of these so-called inorganic constituents, are really in intimate combination with the same cellular matter of the various cells of a plant, for it is extremely difficult to remove these bases from paper and from woody substances. Paper, though heated repeatedly with hydrochloric acid, always leaves a weighable quantity of ash, by which the chemist in his quantitative analyses is often materially disturbed. The proportion and composition of this ash are different in different kinds of organic tissue, and no doubt are also different in the different kinds of elementary forms, from which these tissues are produced. If, therefore, the same cellular matter is used in plants to form very different systems of cells, we are in the wrong to assume that those different forms consist of the same materials. As the chemical tendency of every base, and of every different quantity of the same base is different, it must produce an effect different in nature from that caused by another base, or another quantity of the same base, though united with the same cellular matter. This effect is characterised, first, by making the same cellular matter assume different forms, and secondly, by making it exercise a different influence on other bodies, and so causing it to produce a variety of different substances owing to those different forms.

All we have just stated with regard to the cellular matter of plants, is also applicable to that of animals. The gelatinous tissue has a prominent place in animals. The serous membranes, the tissue of the epidermis, the cellular tissue beneath the epidermis, and that of which the bones are composed, all consist of gelatinous tissues. If the matter that can assume those four external forms were completely identical, no difference either in form or in function could exist. On the other hand, a difference in form and function indicates a chemical difference either in the composition or in the constitution of a substance. Both the composition and constitution of the gelatinous matter, wherever it is found in the animal body, are the same; but what are commonly called *admixtures* are different in different tissues, and therefore this gelatinous matter cannot be always called

the same animal substance in an organic sense. A small difference in the proportion of basic phosphate of lime,

$$3\ Ph\ O^5 + 8\ Ca\ O,$$

changes it immediately into another chemical substance in the animal body—produces a different relation among its elementary parts, so that as a whole, it assumes a different appearance—makes it perform other functions—and thus gives rise to those differences which could not exist, did the substance remain the same.

Since, therefore, we see in the organic kingdom so many different forms produced by the same organic substances when combined with different inorganic substances, and such very different functions performed by the same organic groups, chemists ought to make it their task to examine those admixtures hitherto neglected, which, in all our analyses, we are accustomed to designate by the unworthy name of *ash*. When the elementary tissues are destroyed and this *ash* is examined, the paradoxical idea,—which now, to the great disadvantage of science, is gradually gaining ground, that similar substances produce dissimilar ones,—will vanish. Thus an end will be put one day to that predominant hunting after the discovery of identity, by which some chemists are now so powerfully governed. True it is, that the materials of the organic kingdom are but few in number, but the inorganic admixtures are infinitely variable in nature and proportion, and hence the substances resulting from their combination, as they exist in organic nature, are infinitely variable also.

I will not repeat here what has been remarked before, (p. 314), with regard to the difference between the albumen and fibrin of the blood, a difference of 0.3 per cent. of sulphur, which, however, is sufficient to cause the difference between these bodies; nor do I repeat what has been said (pp. 61-63 and 73), about the different arrangements of the same organic molecules, by which a substance may be identical with others in its composition and in its reactions, but, at the same time, chemically different in a dynamical point of view. I refer, however, to the places just mentioned, because the explanations there given will equally apply to those polymorphic

conditions which we observe among organic substances; and, therefore, I am convinced that there is, in the organic kingdom, no difference of form in any tissue which is not based on an essential difference in the materials constituting that tissue.

The invaluable investigations, which of late years have been made with the microscope, have proved, that organs performing the same functions consist of the same kind of tissue; whilst those performing different functions consist of different tissues. This leads to the just conclusion, that the form of the parts of which an organ is built up, or by which a function is performed, is in close connection with that function itself, and that, on the other hand, the function is dependent upon the form. If the form be really dependent on matter and the forces residing therein, the function is dependent upon this also. In organic nature, therefore, matter, form, and function go together, and the one being different, the other will necessarily be different also.

This view of the subject applies as well to all the sickly conditions of any organ, or of the whole organism, as it does to all the healthy functions of plants and animals. The connection existing between different organs of the animal body by nerves and vessels, and both of the animal and vegetable body by cells, is of such a kind, that Bichat's wish —that the organism might some day be made divisible into such simple parts, that conceptions of vital action might be attached to them, equally simple as those of gravity, elasticity, &c., connected with unorganised bodies,—will probably never be realised. But although these conceptions will never attain the greatest possible simplicity, as regards the connection of the constituent parts in an organic whole; we can, nevertheless, approach to that simplicity, and we do approach to it now that we have commenced to establish a connection between form, matter, and function.

For these reasons a brief survey of the elementary forms of organised parts is at present peculiarly suitable. Where we have as yet but insufficient knowledge of the mutual connection of form, matter, and function, which is too often the case, it will be useful to become acquainted with the

forms, though it be only as a part of the chemical history of the organic body. The chemist ought to see something more than gelatine in gelatinous tissue, and the histologist something more than fibres of a determined form. It appears to me, that it is equally necessary for the chemist to know the elementary forms of the tissues, as to know that alum crystallises as an octohedron.

It is chiefly to the investigations of Schleiden,* and of Schwann,† that we are indebted for our knowledge of the elementary forms of the organised parts of plants and animals. This knowledge, though now elevated to a separate science, ought to be slightly sketched here.

The whole organism is composed of a great number of small particles, of which the origin and appearance are the same in plants as in animals. These are, however, united together according to rules which are fixed, but different; and hence give rise to differences not only between these two kingdoms, but between different organs of the same plant or animal. Those small particles, therefore, visible only by the assisted eye, are identical in form and developement, but their combinations vary, and so do the functions performed by them, because the matter of which they consist is different.

Among their first actions are to be reckoned their mutual combinations, and the transformations which they themselves undergo through each other's influence. Although the different substances of which they consist in plants and animals, and in their several organs, can be divided only into two main groups, yet they produce, when combined, the appearance of totally different bodies, of which the actions are as different, as are the combinations produced by the same elementary forms. Wherever in the vegetable or animal kingdom tissues are found, they are simply groups of the same elementary forms which organized substances assume. As the functions of these tissues are different, so is the manner in which the elementary forms are arranged.

* Schleiden, in Müller's Archiv., 1838, p. 137. Beiträge Zur Phytogenesis.

† Mikrosk. Untersuchungen, Berlin, 1839.

When treating of the organic parts combined into one whole, and which then perform a combined function, we must, therefore, distinguish, 1°, the elementary forms which the organic substances assume; 2°, the manner in which these elementary forms are changed; and 3°, the manner in which the secondary forms are combined with each other. The latter is called the *doctrine of tissues*.

The elementary forms which organic substances assume when in the act of organisation, are generally, according to some *always*, little vesicles which can be perceived only under the microscope. They are called elementary cells, kernel cells, primary cells. These are the original forms from which all, or at least the greater part of the tissues appear to be derived. In the simplest form which they possess, when found in growing vegetable and animal parts, they are small microscopical vesicles filled with a fluid. That fluid is often granular; the vesicle is formed of a thin membrane in which a kernel or nucleus is to be seen,—pretty generally in animal cells, but in vegetable cells chiefly when they are newly produced. It is this elementary form found in so many tissues of plants and animals, by which organised substances are distinguished from unorganised, and from which the most different organised bodies are produced. In a word, from this form the organic kingdom originates, and by it, it is sustained.

This almost universality of the same elementary form assumed by the most different chemical bodies, when in the act of organisation, is highly remarkable. Schleiden has observed it in vegetable, and Schwann in animal parts, and it appears to be identical in both. It has been recognised in all kinds of animal fluids, for instance in the corpuscles of the blood, in the lymph, mucus, pus, and in almost all the solid parts of the body. Even the embryo of a new being is merely such a vesicle filled with liquid, and containing a kernel. A great number of philosophers, among whom Purkinje, Valentin, Henle, and Turpin stand prominent, have paved the way to this discovery for Schleiden and Schwann. The two latter have enlarged it to the greatest extent, and have laid down

as a general rule, that under the microscope we observe in all growing organised substances always and ever the same elementary form, from which everything is afterwards produced.

The investigation of these elementary cells has shown, that if their walls are dissolved by any liquid, the kernel is almost always left behind. This kernel has, therefore, an existence of its own; it is called *cytoblast*, *nucleus*. Sometimes it exhibits one, two, or more dark little spots which have the name of *nucleoli*. We are not fully certain of the nature of these nucleoli, and it cannot yet be made out whether they are openings, vesicles, or solid little spheres. They are situated at the internal wall of the kernel.

The kernels themselves are considered as little cells; they are united with the cell, and constitute a very perceptible part of it.

The cells themselves are surrounded by a fluid of variable liquidity, which, as the tissue grows older, increases in consistency, finally becomes solid, and constitutes the material by which the cells are connected together.

The manner in which the cells or main forms of the organic kingdom are produced, is thus represented. In a shapeless, consistent, sometimes almost gelatinous mass, to which the name of *cytoblastema* has been given, containing the materials requisite for the production of cells, small round grains (nucleoli) are perceived in the act of formation. Round these grains a layer of a granular matter is deposited which continually increases in thickness, and constitutes the kernel (nucleus). This kernel is an oval shaped or round little body which is almost always opaque, and has a granular surface. It is considered to be a vesicle, a little cell itself. From the surface of this kernel a small vesicle is raised, appearing as a segment of a sphere. This vesicle is very thin and transparent. In the beginning it is smaller than the kernel, but it soon expands itself, and becomes so large that, when it is full grown, the kernel lies as a minute corpuscle upon its interior wall. The material from which this vesicle is produced is supplied by the cytoblastema, and converted into a vesicle by the kernel. Thus it appears, that the

nucleolus is formed first; its embryo must exist in the cytoblastema, the thick organic fluid. The first trace of organisation is the production of a small perceptible body,—this nucleolus—which deposits upon its surface a granular substance from the cytoblastema to give rise to a little producing organ, the kernel or nucleus. This kernel transforms the cytoblastema into a granular substance, adhering to its surface, and from which the cellular membrane originates. Whilst the granular substance of the cytoblastema becomes more and more condensed by the nucleus around its surface, this membrane is at the same time expanded, filled with a liquid, enlarged and thus transformed into a vesicle in which the kernel, the producer of the vesicle, remains enclosed. The kernel and the nucleolus remain adhering to a certain spot of the cell-wall, whilst the cell is filled with a liquid varying according to the nature of the organs which are to be produced from it.

If two nucleoli lie close to one another, the granular matter which each of them produced, runs together and becomes one solid mass. Each nucleolus continues to secrete its own liquid, but as the exterior layer of this liquid has solidified into a common one, from which the wall of the cell kernel is formed, only one cell is produced, containing one kernel and two nucleoli.

If we assent to this view of the formation of the cells, which is represented by Schleiden and Schwann, though not entirely approved by Henle* and others, we are obliged to pre-assume that there must always be a kernel present in the cells. In the cells of many cellular systems, however, whilst in the act of formation, no kernel is perceived, or at least in their kernels no nucleoli are found. Such cells occur, for instance, in the cryptogamia, in many phanerogamia,† and also in animal bodies. Schwann accounts for this by supposing the absorption of the kernel of the nucleolus after the cell has been duly formed.

These and other observations cause, as yet, much difference of opinion among botanists and zoologists, as to the pro-

* Lehre von den Gewebe, Leipzig, 1841, S. 154.

† Wiegmann's Archiv. 1839, Bd. 2, S. 19.

bability of the explanation we have given above of the formation of cells. Those who are engaged in the investigation of the origin of animal tissues, generally attach themselves to the views of Schleiden and Schwann, more than the botanists do;—at least they consider kernels as generating groups of molecules, although these kernels in the animal organism do not always produce cells, but often bodies of a different shape. In many vegetable cells it is difficult to find kernels, but in animal tissues, when in the act of formation, this is very easy. Even in elementary parts of animals which have long since lost the cellular form, and have assumed an entirely different shape, the remnants of kernels are very frequently found.

Some botanists do not make any mention of the cell-kernel, as an original and active part; at least, they attach no value to its appearance. Mirbel, for instance, states that a mucilaginous substance, called *cambium* by him, (Schleiden's cytoblastema,) whilst becoming granular and gelatinous, has the appearance of little flocks, which, on closer inspection appear to be cavities (to which he gives the name of cellular cambium). These cavities increase in size, and constitute the cells. The cambium is present both in and without the cells. It is produced from the vegetable juices that are the most highly organised, and among the dicotyledons, in woody plants, it is internally secreted by the inner bark (liber).

The explanation which Mirbel has given to the formation of cells, scarcely deserves that name. As the phrase *vegetable juices that are the most organised* means nothing, it does not bring us any farther on our way. Mirbel, however, does not speak at all of the kernel, as an active organ of the cell itself, and thus he in fact rejects what Schleiden and Schwann have established in regard to the formation of cells. Jussieu and others reckon the kernel only among the contents of the cell, and therefore give it no value whatever as a generating organ. My experience in this respect is far too small to enable me to pronounce any decisive opinion.

As regards the so-called cambium, the name has been applied to different things at different periods of the more

recent scientific investigations. In herbaceous plants it is the source from which a great many organs are produced and nourished, and is highly worthy of consideration. In other plants it possesses properties different from those which it exhibits in the herbaceous; nay, it is different for every genus,—for every species. Hence the reason, why not only the general but also the specific substances which plants contain are to be found in the cambium.

It is usually semi-transparent, filled with little globules. Mirbel and Payen call it *matière globulo-cellulaire.**

In young, and in all herbaceous plants it is very rich in nitrogen, owing to the presence of albumen, legumin (?) &c., which it holds in solution. It contains the material for the production of cellulose in the state of dextrin; besides starch, gum, sugar, mannite, and perhaps also those substances which are deposited in layers upon the cell-walls, such as extractive matters, salts, acids, &c.

Thus it is evident, that the term cambium means the same thing in plants, as cytoblastema in the whole organic kingdom, viz., a substance containing the materials from which cells can be produced.

What may be regarded as established concerning this substance is, that, in plants, the chief constituent it contains, is cellulose in a soluble state, or dextrin, whilst in the animal organism the formation of cells can proceed in various ways from bi- and tri-oxide of protein. The active constituent of the cytoblastema in plants, therefore, is *dextrin*, in animals frequently bi- and tri-oxide of protein.

Mohl has also published a few observations on the cell-kernel, which are at variance with those of Schleiden above mentioned.† Schleiden states that the cell-membrane grows from the kernel, and that the latter continues to form a part of the produced cell-wall. Mohl, on the other hand, thinks

* Comptes Rendus, 16 Jan. 1843, p. 98.

† Bot. Zeitung, 19th April, 1844. The Bot. Zeitung of 12th April, 1844, contains a brief account of a dissertation by H. Karsten, De Cella vitali, in which also Schleiden's theory is rejected. I have not been able to obtain that treatise before this sheet was printed.

that the kernel is enclosed by the cell-wall as by a bladder, and does not exist *in* the wall, but sometimes at a certain distance from it, even when the cell is in the act of formation. In such cases, therefore, the kernel has no direct connection with the cell-membrane. Schleiden further holds that the membrane, which afterwards constitutes the exterior envelope of the cell, is the *first* produced, whilst Mohl considers the primordial tissue, *(schlauch,)* which afterwards entirely disappears, as the first cellular membrane, (see hereafter, *Cell-wall*;) for, according to Mohl, in this primordial tissue, the kernel either lies within or close to the interior wall, and is subsequently detached from it,—or little threads are thrown out from the kernel through a mucilaginous envelope, by which the kernel is connected with the primordial tissue, so that the kernel is sometimes found in the midst of the cell, like a spider in its web. In other instances the whole space between the cell and its central kernel is filled with vesicular parts, of which the walls consist of the same mucilaginous substance of which the above threads are composed.*

According to Mohl, therefore, the nucleolus is not the generator of the kernel, nor the kernel of the cellular membrane.

Valentin has recorded similar observations,† and especially this one, that the kernel in some animal tissues does not directly adhere to the cell-wall, but that threads proceed from it in a cellular form, which are the only means of connection between the kernel and the cell-wall, or other contiguous parts.

We are therefore as yet uncertain in what respect the kernels assist in the formation of cells.

Bergmann‡ has further found, in examining the eggs of the frog and the salamander, that the yolk, at the very commencement of its developement, consists entirely of granules of equal size; that these granules first arrange themselves in a few large groups, then divide themselves into smaller

* See hereafter, *Cell-wall.*

† Wagner's Phys. Wörterbuch, p. 625.

‡ Müller's Archiv., 1841, S. 92.

groups, cemented together by means of a viscid substance, and are finally surrounded by a vesicle, which is the cell-wall. In this kind of cell-formation in these eggs, there are necessarily many nucleoli present, which, together, are the particles that produce the contents of the cells, whilst the cell-wall is probably formed from the viscid cementing material between the little granules. If we are to assume this hypothesis of the cell-formation in the eggs above mentioned, which is entirely different from that represented by Schwann as taking place in vegetable and animal tissues, the nucleolus is not the omni-generating part,—viz., of the kernel, the contents and the walls of the cells,—but a cell is an organic agglomerate of a large number of small granular particles, having the size of 0.001 to 0.002 of a millimeter, and which, when uniting together in the above manner, give rise to the existence of a primary cell.*

Whatever view may be taken regarding this formation of the cells,—whether one or more parent nucleoli exist in each of them, or the vesicle be developed from the kernel, or from an agglomerate of granules enclosed by the vesicle, there is no doubt that these granules, from which cells are formed, do exist. They are always found wherever new cells are about to be produced. They are, therefore, the smallest organised molecules now known, and must be regarded as the elementary forms of all the organised masses, because they appear to be indispensable for the formation of cells, and either *assist* in their production, or do really produce them. The cells are further to be considered as the building materials of the tissues in plants, and of many tissues of the animal organism.

These elementary granules have various forms. Though neither their organic nor chemical characters are yet sufficiently known, to enable us to divide them into regular classes, or to establish a connection between their form and composition, yet important differences have been observed in their several forms. In mucus and pus, for instance, where they adhere together, they are, after separation, of a flattened appearance,

* Henle, l. c. p. 162.

whilst in the yolk they are found to be oval-shaped, cuneiform, and cubic.*

If these different forms do really exist, they represent, no doubt, so many chemically different bodies (p. 73,) of which the composition in the hundred parts may be different, of which the elementary arrangement—though in the yolk they may be all protein compounds—will certainly not be the same, and of which the effects in producing such a great variety of forms are therefore to be traced to substances of which the chemical nature is essentially different; for we have to regard the various forms assumed by those elementary granules, as the effects of molecular arrangement, just as we do the crystallisation of different chemical substances. Those oval-shaped, depressed and other forms of the elementary granules are as essentially connected with the chemical composition and constitution of the organic bodies, as the crystalline form of sulphate of soda depends on the formula $RO\,SO^3$; and so together with those various forms, the functions of these elementary granules, though in the normal secondary form they might invariably be arranged into cells, are dependent upon the chemical substance of which they severally consist.

When, after all this, the skilful and conscientious observer, Henle, tells us, (p. 163) that those elementary parts consist of a vesicle filled with fat, and that this vesicle is probably a protein compound, we cannot help reflecting, even while we pay due regard to the arguments drawn by Ascherson, from the metamorphosis of albumen by means of oil—how far we are yet removed from a thorough knowledge of the elementary forms of the organic parts. There can be no doubt that among these elementary granules the greatest diversity exists. This diversity need not extend to the substances produced from them, yet it will be more or less in proportion to the composition of the tissue that is formed from the cellular systems which are produced from the elementary granules; for if the cells of plants and the corpuscles of the blood, the globules of starch, and the granules of the pigment of the

* I quote this observation on the authority of others. It requires to be repeated.

eye, were originally all vesicles of a protein compound, filled with fat, it would be for ever impossible to institute any investigation as to the chemical origin of the several tissues—no intelligible conception even could ever be formed of it.

It is very probable that a protein compound does exist in the elementary granules, either constituting the whole or a part of the envelope, or contained as a solution within the vesicle. This assumption is based on the fact that, even in the youngest organic products, both of plants and animals, protein is never absent, and therefore belongs to the first requisites of organisation; and besides, the facility with which protein can be decomposed, seems to render its presence indispensable for any kind of organisation. The animal body cannot here afford us an illustration, because it cannot exist without protein; but in the vegetable kingdom, in which non-nitrogenous substances, such as cellulose, incrusting matter, dextrin, starch, sugar, pectic acid, &c., predominate; even there it is proved by experience, that organisation cannot take place without the presence of protein. Even the most simple mould plants,—produced from non-nitrogenous substances, such as milk-sugar, tartaric acid, and water, under the influence of atmospheric air, (*i. e.* of nitrogen)—contain protein from the very first moment of their production.

Hence protein is to be considered as a substance indispensable to the formation of cells; and it is even very probable that the elementary granules contain protein previous to that formation, this protein being the first source of organic action.

But we must not allow ourselves to be deceived by the appearance of possessing a knowledge to which we have not yet attained. Until we are thoroughly acquainted with the chemical character of those elementary granules, any pure chemical physiology must of necessity be defective, for these granules are the original, the fundamental organs. We must attempt to examine them by reagents and under the microscope, to find out what are the definite forms they assume, to bring their forms into connection with their properties, and finally to com-

pare these properties with those recorded of peculiar chemical bodies. By doing this, we shall advance a most important step on the way to a knowledge which is destined to teach us how the building materials of the organic kingdom are connected and transformed.

We are compelled to confess our ignorance, not only of the composition of the elementary granules, but also of the way in which they are produced. Probably they are the first organic, and certainly, the first organised substances produced from the so-called inorganic matters in plants. They contribute in the most important manner to the formation of kernels, cells, cellular systems, and tissues. They are, therefore, or rather the chemical bodies of which they consist, are the main source of organic activity. If cells are really produced from kernels, and if, as is said, these kernels are themselves vesicles filled with a fluid, then not only are the cells, or other forms, produced from these kernels, but the elementary granules themselves are the elementary organs, and the kernels are organs. compounded of these: or more correctly, perhaps, individuals which, however small they may be, act as an organic whole, and therefore in a complex manner. This action, when resolved into its constituent parts, has its basis in the nucleoli, these again in the elementary granules, and the latter finally in the four elements that constitute the small groups of bodies which, together, produce a vesicle filled with fluid, *i. e.*, a cell-kernel.

Returning once more to the manner in which nucleoli or elementary granules are produced, I think Ascherson's opinion is inadmissible. He assumes that the globules of milk and pus, nay, all kinds of elementary granules, are formed in a manner analogous to what he has observed in the case of albumen, which, when brought into contact with oil, forms a little cell, filled with a drop of oil. Casein, albumen, and fibrin, in solution, may have the property of separating fat into globules; they may form a layer or membrane around a drop of oil, and so prevent the oil from running together. This property is possessed by gum arabic also, and even though it were possessed by no other substance whatever, a

passive layer of a solid substance around a fluid is entirely different from an *active* membrane, from which manifold actions proceed in organic nature. Such theories tell us nothing more than does the formation of froth in soap water.

Equally worthless is Raspail's opinion that fat, supposed to form the contents of the elementary granules, would become a protein compound by taking up nitrogen. When questions of this kind come before us, our best course is to confess our ignorance, and we shall thus render greater service to science, than by attempts to answer them so unsatisfactory as these.

Finally, we have to remark, that any comparison between the formation of crystals and that of elementary granules, with the cells produced from them, like that instituted by Schwann, may be called fruitless. It appears to me that such comparisons show the reverse of what they are intended to do—they show diversity arising from identity. There exists in the peculiar nature of the organic elements—carbon, hydrogen, nitrogen, and oxygen,—a source of diversity, perceptible not only in its final effects, but in all, even the most simple, actions of the substances produced from them. The very simplest of these actions is doubtless the production of the form which they assume, when arranging themselves into the smallest particles that we can perceive. This form is either globular or nearly so, representing a vesicle filled with a fluid.

It is equally accordant with the nature of a cell, to consider it as an organ, or even as an individual. It has the power of generating other cells like itself, and does really produce them, though not always. There are some cells, which, according to the idea that still prevails, but which I have not been able to confirm by my own observations, are born from and within a parent-cell; others are produced without it, others again do not require the co-operation of a parent-cell for their production. The first mode of cell-formation is called endogenous, the second exogenous; a third manner is called division, a fourth independent cell-formation. In whatever way this increase of cells takes place,

there must always be materials present that can supply the constituents of the new cells; *i. e.*, a fluid in which the future materials of the new cells are dissolved, and from which they can be converted into a solid and organised form. Two epochs or moments, therefore, are to be distinguished here; first, that of the *production* of organic matter fit for the cell-formation; and second, that of its *solidification* into cells. The latter point is what we are now treating of. We assume, therefore, that there must be a fluid present in which the materials are already prepared, but from which they are to be separated.

Whenever new *endogenous* cells are produced from existing ones, the materials are enclosed within the vesicle. This formation takes place within the cavity of the vesicle itself. It is met with in phanerogamic plants, and also in several animal organs. The process is said to be this, that from the contents (cytoblastema) of a duly formed cell, nuclei and nucleoli are formed in the way mentioned above (page 355), and these nuclei are expanded into cells. Whenever, therefore, from the contents of one single parent-cell several young cells are being formed, the membrane of the parent cell must necessarily be expanded, enlarged, thinned out, or absorbed, and finally it will disappear. In the same manner a system of cells of the third generation is developed in those newly produced, the cells of the second generation disappearing in their turn. Now, if only one young cell were produced in every parent-cell, this increase would be of no avail for the increase of the number of cells. It is necessary, therefore, that several young cells come forth from one and the same source within the parent-cell, the latter being thus replaced by a number of new cells. Schleiden states that this actually takes place. When, for instance, the contents of one cell give rise to the production of four small cells, by which the parent cell is expanded, thinning out its walls (which are afterwards to be absorbed), then the number of cells is increased by three. If, from the contents of each new cell four others are again produced, those of the second generation disappearing, then there are, after the third generation, sixteen cells; after the fourth,

sixty-four, &c. It is always the *kernels* of the new cells that produce other new cells, and the old cells disappear.

If, however, we consider this cell-multiplication from a chemical point of view, several facts remain unexplained; several facts even require to be confirmed by a greater number of observers. Is it certain, for instance, that the nucleoli are the first things produced, and if so, are they the generators of kernels, and the latter of cells? If this be free from any doubt, the following questions present themselves:

What is the cause of the first production of nucleoli? In what way are they produced from the cytoblastema (in endogenous plants from the contents of the cells)? Does this production take place by, or entirely without, the influence of the kernel of the parent-cell? Do the contents of the parent-cell possess the power of arranging themselves into nucleoli, which, being now little organs endowed with powers of action, are able to produce kernels, which in their turn produce the cellular membrane?

These, and several other questions, we are still unable to answer, even when we confine ourselves to exogenous plants, in which nucleoli, kernels, and cells are produced from liquid organic substances external to the cells, that is to say, without the influence of cell-walls and kernels.

But whatever conception we may have of the cell-formation, it is entirely undeniable, 1° That, as there are soluble inorganic substances, which in certain conditions crystallize, so there are soluble organic substances, which in certain conditions form nucleoli, kernels, and cells. 2° That these little organs maintain themselves, and preserve their specific characters, as individuals do by generation, according to the universal law of organic nature, that, the conditions being the same, like produces like. 3° That the endogenous formation of cells is the result of the conversion of organic substances into such as are similar to those of the generating cell itself. The substance must first be made similar to that which has a form, before it can assume that form. 4° That the generating cell, therefore, has but one function to perform—the preparation of a substance, identical with that of which itself

consists. This substance being once prepared, its organisation is as inevitable a consequence, as crystallisation is a consequence of the mixing of nitric acid and baryta water,—of sulphuric acid and potash, &c. 5° That the parent cell, therefore, does not give a form to the young cells, any more than a mother gives a form to her child. A generating being does nothing more than secrete a substance, which, under certain circumstances, can assume a form similar to that of its parent. In this respect there is no difference whatever between the propagation of the higher animals, and the multiplication of cells.

The *exogenous* cell-formation takes place in a manner similar to that of the endogenous, with this difference only, that the young cells are formed without the parent-cell, the liquid containing the materials for the formation of new cells (cytoblastema) existing not *within*, but *without* the parent-cell. This does not constitute a real difference, because the cytoblastema, which in the endogenous process exists within the cell, is not more subjected to the influence of the cell-wall than the fluid that surrounds the cell without. This cytoblastema contains the materials of new kernels and cell-walls, and it makes no difference whether the new cells are formed on the exterior, or on the interior face of the walls of the parent cells. These walls have the power of assimilating the organic substances that are present to those which they themselves contain; and they can, without, as well as within their cavities, produce new individuals or new cells from nucleoli which are in the act of self-separation.

Considering, however, the difference in position between the old and new cells, as produced by these two modes, it is evident that by the exogenous process cellular systems are produced, which are different from those that are the result of the endogenous process. Hence this process is of importance in the general study of the origin of organs. It can be observed in cryptogamic plants,—for instance, in mould plants. These two modes of cell-production, therefore, consist in the formation of substances according to chemical laws;—substances which, once formed according to general

laws, are converted into cells. The walls of the parent-cells cause the preparation of these substances, but do not produce the new cells; hence the name of parent-cells is applicable to them only to a limited extent.

With regard to the absorption of the walls of the parent-cells, we have to remark that this is not a requisite in the exogenous process. The old cell may remain unaltered, which is not the case in the endogenous process. Hence an important difference arises between these two modes of cell-formation.

It is not proved, however, that in the endogenous process the walls of the parent-cells are absorbed, as is generally believed; it is only shown that they disappear or become invisible. If they disappear without being dissolved, then they must become expanded and must *split*, being deposited as thin films round the new cell-walls, and becoming identified with them. If this take place, these cell-walls will be organically different from those propagated by the exogenous process, which cannot be increased in thickness from such a cause. If in the endogenous formation the old wall be absorbed, then there results an important physiological difference between it and the exogenous process, because in the latter cellulose is produced within the plant, in the form of a solution from which new products are to be formed. Hence it follows, that it is a matter of the highest interest to ascertain, whether or not these walls are really absorbed. If such an absorption or dissolution of the old cell-walls take place in animal cells, this would partly serve to explain the production of several secretions, such as bile, urine, &c. It requires, however, a more ample investigation to determine whether such an absorption does take place in full grown individuals. (See *Secretions*.)

There is a third mode of cell-multiplication, which is called *division*. Within the cell laminæ are produced, by which the internal space is divided into two. Other laminæ place themselves at right angles to the former, so as to divide the whole into four compartments. This division is continually repeated around a central point, till the whole is *subdivided*

into little groups, in the interior of which there gradually appear granular particles, nucleoli, kernels, and finally cells. Bergmann states, that such a subdivision takes place in the yolk of the egg (p. 359). From the surface a partition-film is formed within the yolk. This film penetrates into the interior in the form of a lamina, and thus divides the yolk into two equal parts. Another lamina is formed at right angles with the first, and so the whole is divided into four. Subsequently various diagonal laminæ are formed, and so the whole is finally converted into an agglomeration of little groups, which are likewise separated from each other by concentric laminæ. Those little groups consist of particles, which are at last transformed into cells. These laminæ are at first visible, but afterwards disappear, and are replaced by cell-walls.

If such a cell-formation, coinciding with a cell-multiplication, does really take place, then in all cases where a division is effected, we should be induced to view the cell-formation in an entirely different light from that in which it is represented by Schleiden and Schwann. The several cells are in this case entirely the products of a division, which is independent of the molecules of which the cell is originally composed. These molecules retain a passive organic character, until the division externally has been completed, and it is not until they are united into an independent little group, that they begin to exhibit the peculiar phenomena of vital action. In the case of such a division, the operation would commence within the large cell, or on certain fixed places of the wall, and so the first organic action would proceed from molecules that are situated in the wall.

It is very difficult to reconcile these alleged facts with the observations of Schleiden and Schwann on the endogenous formation of cells: and they envelope the whole subject in still deeper mist.

The more recent observations of Bischoff,* and especially of Kölliker,† have thrown a new light upon this subject, and

* Entwickelungs-Geschichte des Kaninchen-Eies, 1842.

† Entwickelungs-Geschichte der Cephalopoden, 1844.

have entirely reconciled the third mode of cell-formation—that which is called *division*, so far as eggs are concerned—with the first or endogenous process. Observations, however, upon which sufficient reliance may be placed, have proved that in the vegetable kingdom there is a mode of multiplication of cells through division by partition walls. One cell is changed into two, by the formation of such a wall; in the same way the new cells are divided into two, &c. These partition walls place themselves at right angles upon the old cell-wall, and it is by them, without the co-operation either of kernels or of nucleoli, that the cells are multiplied, in a manner exceedingly simple, but entirely different from those formerly mentioned. In the Phytolacca decandra, for instance, such partition-walls may be most distinctly seen in the act of formation within the cells of the pith and the parenchymatic layers of the epidermis, dividing one cell into two. The cause of the production of such partition-walls is involved in darkness, but the fact itself is beyond all doubt. This well-confirmed mode of cell-multiplication, whether it take place frequently or rarely, makes the theory of Schleiden and Schwann far less universally applicable (see *Utriculus internus*, hereafter).* It does, however, by no means follow from this, that the first cells of such plants are not produced according to their theory of cell-formation.

Besides these, there is a fourth manner in which cells are produced and propagated. I mean the *spontaneous* process. It occurs in equivocal generation, in every case when unorganised, though organic, bodies give rise to individuals; in various products of disease; in exsudations in wounds, for example, that are healed by plastic lymph; in fractures of the bones where an exsudation gives rise to a great many new cellular series; in pseudo-membranes; in many secretions, in those, for instance, which are produced by the application of blistering substances, &c. The organic fluid which is called cytoblastema, can spontaneously assume the cellular form. Originally a homogeneous and semi-fluid mass, small granu-

* Compare Harting in Tydschrift voor natuurlyke geschiedenis, 1844.

lar particles, nucleoli, and nuclei successively appear in it, which give rise to cells in the same manner as in the endogenous and exogenous formations.

This last or spontaneous mode of formation is very frequent, and always takes place when organic, though unorganised, matter assumes the cellular form; for instance, when either mould plants or infusoria are produced from infusions of organic substances, &c.

It is my opinion that the first, second, and fourth modes of cell-formation may be simply represented thus:—the endogenous and exogenous, as regards their cause, may be reduced to one. From what appears to have been established with regard to animal tissues, they may be said to consist in the formation of organic molecules, which form nucleoli, and which again give rise to kernels, from which either cells or other forms derived from the kernels originate. This is therefore a real monogamia, for like produces like:—a particular cell is the parent of similar ones. The substance of which the cell consists, transfers an impression to the substances which exist within or around the cell. The first effect of that impression is the production of nucleoli, and these being once formed, new centres of operation are established, fitted to produce kernels, and through these again cells and other forms.

This is the limit of the explanation given by science; it cannot go any farther, because observation stops here.

Hence, it appears, that the formation of the first nucleoli is involved in the same obscurity, as the formation of the first particles of crystals (p. 70). All we know is, that by the formation of these nucleoli, *active* and *ever-generating molecules* are brought into existence, which do not exist in the inorganic kingdom.

We see from the spontaneous cell-formation that the existence of a cell is not always necessary to produce the first tendency towards the formation of nucleoli. If this tendency is imparted by a cell, then the latter determines the direction of the former, without being its cause. That organic molecules, under certain conditions, can assume the cellular form with-

out having received an impulse from any existing cell, is most distinctly shown by the spontaneous cell-formation, that is, where no original cell existed; for instance, in moulds produced from milk-sugar, and in innumerable other instances. In both endogenous and exogenous cell-formation, therefore, the cell does not originate the force, which is already in action in the materials of the cytoblastema, but simply determines the direction of its operation; or it awakens the activity of the adjoining substances. Hence, finally, we may deduce the general principle,—that there are some organic molecules, which, in certain conditions, are able and strongly inclined to form concave spherules, just as inorganic substances assume other symmetrical forms. In vegetable bodies, cellulose, $C^{24} H^{21} O^{21}$, appears to constitute the basis of almost *all* the cells, and out of it almost *all* forms are developed; in animals, a similar basis, in many cases at least, appears to be afforded by the binoxide of protein, $C^{40} H^{31} N^{5} O^{14}$. The cells being once formed, both of these fundamental substances may, in whole or in part, be replaced by other substances, and are really often so replaced. Hence the variety of tissues which occurs in different plants and animals. Finally, as regards the multiplication of cells by division, no cause of any satisfactory character can as yet be assigned for it.

B. Elementary Forms of Inorganic Substances.

If we confine ourselves to the perceptible form which the smallest particles of inorganic substances can assume, then the series of solid bodies is the only one left for our consideration, as the gases and liquids escape our observation entirely. The organised parts, however, are all either solid or very nearly so. If, therefore, the present state of our knowledge admits of comparative study, the opportunity is afforded for it by microscopical investigations into the origin of solid organic and inorganic parts.

The latter have been investigated with much care by Harting.* He has brought together, under the microscope, solu-

* Bulletin, 1840, p. 287.

tions of pure chemical substances, which exercised upon each other a known chemical reaction, and then examined the phenomena exhibited. By the kindness of Harting, I have some years ago been made acquainted with his results.

His opinion is, that inorganic substances, in so far as they can be made visible by a powerful microscope, assume four principal forms. These are, the *crystalline form*, the *molecular form*, the *transparent membranaceous form*, and the *gelatinous form*. Other forms are produced from these four, either by means of their mutual combination, or by accumulation of the particles, in consequence of the liquids used for precipitation being highly concentrated. According to Harting, therefore, the above four forms may be considered as the elementary forms of the microscopical inorganic solid particles.

1° The *crystalline form* does not occur very frequently. Iodine assumes this form, when to its alcoholic solution water is added; so do sulphate of lime, when precipitated by sulphate of soda from a solution of chloride of calcium,—and phosphate of lead, when thrown down from nitrate of lead by phosphoric acid, &c. A slow precipitation from weak solutions is not alone sufficient to make substances crystallise, that usually do not form crystals. If this may really be considered as a general fact, it would make us conclude that substances which form microscopical crystals, consist of molecules, which become crystalline upon their first arrangement. To this class, therefore, belong all microscopical particles of complete crystals, whatever may be their character.

2° The *molecular precipitate*, distinguished by Harting, was examined with the same magnifying power as that which was applied to the above minute crystals, which could be no longer distinctly recognised as crystals, if their diameter was less than 1-500th of a millimeter. Thus we can judge of the size of what Harting calls the molecular precipitate, and may conclude that its particles might really be crystalline, and yet the smallness of their size would make it impossible to distinguish them to be so. It cannot, therefore, be asserted that this molecular precipitate is without a crystalline form; all that can

be said is, that it is too minute to enable us to distinguish that form, if it does exist. It was produced in solutions of chloride of gold, when mixed with sulphate of iron (resulting precipitate, gold); of silicate of potash, with hydrochloric acid (silicic acid); of bichloride of mercury with potash (deutoxide of mercury); of sulphate of protoxide of manganese with hydro-sulphuret of ammonium (sulphuret of manganese), &c. It had the appearance of small, roundish particles, of which the precise form could no longer be distinguished. Their diameter seldom equalled 1-1000th of a millimeter. These precipitates have a very strong tendency to combine with each other, and to form either flocks or laminæ. Among all the substances which Harting examined, he found that albuminate of lead alone, after the lapse of several days, still consisted of isolated particles, varying in size from 1-800th to 1-3000th of a millimeter. He estimates the size of the molecules of precipitated sulphur at 1-1500th of a millimeter, and hence one milligram will contain 1687 millions of these molecules. It is these molecular precipitates which exhibit very distinctly the movement observed by Brown—a movement which may be effected by physical as well as by chemical forces, and which, in different microscopic objects, must have a very different origin. Of all the molecular precipitates, those of sulphur and of albuminate of lead exhibit Brown's movement most distinctly.

3° The *transparent membranaceous form* is one of the most beautiful and remarkable forms which substances can assume during their change from the liquid to the solid state. Such precipitates are formed, especially in a solution of sulphate of protoxide of iron, when mixed with potash, (hydrate of protoxide of iron)—of chloride of tin, with ammonia, (oxide of tin)—of sulphate of protoxide of manganese, with ammonia, (hydrate of protoxide of manganese)—of ferro-cyanide of potassium with sulphate of peroxide of iron, (Prussian blue)—of nitrate of protoxide of mercury with ferro-cyanide of potassium, (ferro-cyanide of mercury), and several other ferro-cyanides—finally, in a saturated solution of chlo-

ride of calcium when mixed with carbonate of potash or soda, (carbonate of lime) at ordinary temperatures, &c.

These transparent membranaceous precipitates sometimes extend themselves considerably, and are really thin laminæ, in which, even under very high magnifying powers, not the smallest trace either of globules or any other definite form can be distinguished. They are real membranes, bent or folded in different directions by the confluence of the two drops of the solutions from which the precipitate is produced. After a little while they become wholly transparent, but soon after the greater part is again changed, becomes opaque, and assumes the appearance of distinct particles, formed by the very minute, intimately coherent particles of the membrane, being united into one group. The membrane, however, still continues to exist, but it has become much more fragile. When in this state, its form is called by Harting, *membrano-molecular*;—a form which is occasionally produced directly, for instance, in lime, by the mixture of chloride of calcium with ammonia; in hydrate of peroxide of iron, by the mixture of sulphate of peroxide of iron with potash; in oxide of zinc, by the mixture of nitrate of zinc with ammonia, &c. If it was originally transparent and subsequently became membrano-molecular, its change sometimes proceeds no farther, but sometimes, indeed, generally, the membranes disappear after a little while, being converted into flocks. The molecules of the membrane which are the first perceptible, being formed by the accumulation of the particles of the membrane itself, aggregate and thus increase in size. The membrane falls to pieces, and some flocks are left, which either remain in that state, or, contracting themselves still more, form granules, which are then to be considered as the final product of the mutual attraction of the particles.

But little can be said regarding the nature of the small particles, of which the entire transparent membrane consists. The membrane itself appears on the spot, where the two drops meet from which the precipitate is formed. The contact of the two drops is the *direct* cause of the formation of the membrane. The liquid which is (in ratio of the equivalents)

the less concentrated of the two that meet, loses all that it holds in solution,—this being precipitated by the substance held in solution by the other drop. The precipitation is on that spot sudden and complete, so that no other perceptible effect can arise from the confluence of the two drops; or rather, the precipitate formed in this manner is so dense and coherent, that liquids containing the precipitating substances, can but partially and slowly penetrate it. Hence, I do not think that this membrane presents any analogy with organic membranes, either in respect to its nature, or to the mode of its formation.

The particles, first precipitated, of which the perfectly transparent membrane consists, are, no doubt, exceedingly minute. It is possible, however, that they may be completely penetrated by water, and this may make them, as individual particles, invisible, even by the application of the highest magnifying power.

4° The *gelatinous form*, assumed by precipitates, may be seen—in alumina, obtained by adding ammonia to a solution of sulphate of alumina—in glucina, from ammonia and sulphate of glucina—in silico-fluoride of potassium, from carbonate of potash and fluo-silicic acid. These precipitates are perfectly transparent. This form of precipitate exhibits few or no isolated particles, probably from its being thoroughly permeated by the water which it retains in equivalent proportions. This is likely to be also the case with the membranaceous precipitates, as here, in the first period of precipitation, hydrates may be formed, which subsequently, when the particles are transformed into granules, &c., are decomposed, the product being either another chemical combination between the precipitate and the water, or even an anhydrous body.*

Link's observations are different from those made by Harting,† for he thinks he has seen, that all precipitates are

* Harting has since classed the gelatinous with the membranaceous precipitates (Tydschrift voor natuurlyke geschiedenis, 1843.)

† Jahresbericht, 1840, S. 5; and Poggendorff's Annalen, Bd. 46, S. 258, and De la Formation des Corps Solides. Berlin, 1841.

at first small globules, which unite into large ones, being, therefore, liquid like those of mercury; and that at a later period only, they are converted suddenly into crystals. These globules constitute sometimes laminæ, sometimes gelatinous masses.

According to this view of Link's, therefore, the precipitated crystalline substances are, at first, not crystals, but liquids;—isolated drops, which afterwards become solids. But according to him, the crystallisation is a phenomenon of still later origin than the formation of the solid; and before crystallisation a condition exists, in which the precipitate is composed of small globules, which can be seen when the precipitate produced is examined immediately after the two liquids have been mixed. Link's opinion is, that by the juxtaposition of these globules, the crystal, with its peculiar form, is suddenly produced.

Against this opinion Harting has stated several objections,* and has, we think, succeeded in proving that Link's observations are incorrect. Even with the best microscope the smallest bodies appear indistinct, so that the real form can no longer be correctly defined, and Link's globules ought, according to Harting, to be called simply molecules. Now under this class are to be reckoned particles, of which the diameter is only 1-1000th of a millimeter. Link has spoken of globules of the size of 0.00003 of a millimeter only, but the practicability of such observations is justly negatived by Harting, although it remains probable that the form of the smallest particles of solids is globular.

My own experience of this investigation enables me to testify, at least with regard to the membranaceous precipitates observed under a linear magnifying power of 1200, that their original form is a simple lamina; that they present only at a later period distinctly visible particles, and that immediately after the precipitation nothing is to be seen but a homogeneous membrane, in which, subsequently, distinct particles appear, as is especially the case with the precipitated ferro-cyanides.

This membranaceous form assumed by some precipitates,

* Tydschrift voor natuurlyke geschiedenis.

seems to be the smallest perceptible form in which the solid molecules of the inorganic bodies can possibly exhibit themselves. They are too small to be properly observed and distinguished, and hence nothing positive can be said about their definite forms. We know, however, that they unite together into clearly distinguishable membranes, either of a regular or an irregular form, which, if regular, retain their form unchanged, while fresh particles are precipitated upon them; that thus the smallest molecules first become solid, and are arranged afterwards; that they have each at first an existence of their own, and are afterwards combined together into larger molecules; and that, though there may exist an intermediate state between liquid and solid, the smallest solid particles unite into a large whole, not instantaneously at their production, but only after a certain time. Further, they are joined as solid particles into one large whole, which has often a crystalline appearance, but never occurs as a concave, membranaceous vesicle, never as a generator of some new body, never developing anything in its interior, as takes place in the formation of cells.

The way in which crystals increase in size, is found, not only by Harting, but also by former observers, such as Leeuwenhoek and Ehrenberg, to be,—that a crystalline particle, while floating in the solution, increases insensibly. No further explanation can be given of this process. Link denies this fact. He holds that in this case also small globules adhere to the little crystal existing, and so enlarge it in size. It cannot be explained in what state these particles of solid matter are, when about to constitute part of the crystal. Neither can we understand in what condition the solid matter is, when about to become the first germ of a crystal. But certain it is, that there are no other preceding forms perceptible, and that the first traces of crystallisation are characterised by the production of particles, which, at the first moment they can be seen, are immediately to be regarded as small but perfect crystals. It is unknown, of course, what they are immediately before they become visible, but it is not likely that the very smallest particles of crys-

talline substances which can exist should have a crystalline form.

From the fact of this insensible increase of the size of a crystal, Harting is justly led to conclude, that the layers of a crystal consist of laminæ of imperceptible thickness. Since these laminæ are composed of small crystals, they seem to justify the conclusion, that the particles of crystals are crystalline even before they can be detected by the highest magnifying power we possess, that is, one by which substances of 1-2000th to 1-5000th of a millimeter can be distinguished. Since, therefore, the laminæ increase insensibly, and the crystalline particles of which they consist escape observation, the primary crystalline particle or the kernel of the crystal must be equally imperceptible, and hence we are yet uncertain what may be the real form possessed by the smallest particles of crystals.

C. Connection between the Elementary Forms of Inorganic and Organic Parts.

Various philosophers have attempted to show that there exists a connection between the elementary forms of organic and inorganic particles. These various attempts indicate how important such a connection was considered to be. My opinion on this subject is different. I should consider it to be a new and great difficulty, were such a connection really shown to exist; and a greater still, if there were shown to be an analogy between the smallest visible particles of bodies, of which the one class has to perform a function, for which the other is not adapted (p. 90). The difference which in this respect exists between organic and inorganic substances, must originate with the elements of which these substances are composed, the arrangement of these elements, and the forms which their ultimate molecules can assume.

Even the simplest function of a cell, the production of substances from which a cell can be formed similar to itself, cannot be performed by any crystallised form, much less by any compound organs. An organ made up of prisms or cubes, is inconceivable, much less can it possibly exist.

If at some future period, a conformity should be found between the first perceptible particles of crystals and those of organs, then the knowledge both of crystallography and of histology would be not only retarded, but would remain beyond the reach of man for ever.

This hunting for analogy between the elementary forms of organic and inorganic elementary particles has, no doubt, arisen from a wrong application of the fact, that in the organic kingdom chemical substances are to be found similar to those in the inorganic kingdom, and that the elements of the organic kingdom are all produced from and sustained by the inorganic—a truth which is now fully recognised. But if the elementary forms are the same, whence arises the first difference which produces such different results? Is not a difference in the form of the elementary particles the very first requisite for the production of a difference in the structure of a whole, composed of these particles—in the same manner as differences in the forms of stones and other materials, of which an edifice is to be built up, are requisites for the production of edifices of different forms? Or is it possible, with the same kind of beams and stones, to build edifices of a different form, of a totally different character, and for a totally different purpose?

From whatever side I view the subject, whether from the organic composition of a part of the animal or vegetable kingdom, or from the deposition of the particles of a crystal, or from the function performed by the one but beyond the capabilities of the other;—there must be some point where that great difference commences, which exists between the organic and inorganic kingdoms, and from that point it must advance continually forward in order to render this difference permanent.

If, as we have endeavoured to detail in the first chapter, this difference must have its foundation in the peculiarities of carbon, hydrogen, nitrogen, and oxygen, assisted by some other accessory bodies; then this difference, producing such peculiarities, and of which the performance of a compound function is the last result, must, having that

foundation, be apparent in the structure of the body by which that function is performed—not only in this body taken as a whole, but in the elementary particles of which the whole is compounded. For it is these particles, which severally perform a part of the function which constitutes the character of the whole organ. These particles are organs themselves, and hence neither their structure, nor their mode of production, can be the same as those of the substances which are not organs, and which persist in any state they have once arrived at, till they are removed from it by external causes. This state of permanent activity,—the main characteristic of organs, even the most minute,—requires peculiar forms, and peculiar forces besides, through which both the activity and the form are produced.

Although, therefore, the phenomena of life are only a series of effects of peculiar conditions (combination and forms of substances), still they are equally in want of a fundamental cause, of which the first action necessarily manifests itself,—not by a certain function, for a function is a remote effect,—but by the production of certain forms, which are essential requisites for the performance of the function. Now, in order that such determinate forms may be produced, the germs of these forms must be embodied in the primary arrangement of the molecules; in other words, the first visible form that results from the arrangement of the molecules must be in accordance with the purpose of that arrangement; that is, must have a reference to the future function of the part organised, and this function again must be in accordance with the life of the individual to which that part belongs.

In investigating this connection, we endeavour to discover what means the Deity has used, to give to organised nature its present form. This is THE STUDY OF NATURE. Its aim is to acquire a knowledge of the laws which regulate it—its highest aim, the deduction of even the very remotest results from the very first causes throughout all their phases.

The agreement which has been generally recognised among the forms of the microscopic parts of animals, plants, and inorganic matters, is limited to the analogy in their vesicular

forms. Starting from the theory of cells, every globular microscopic particle which was found in organised substances was called a nucleolus. But where is the connection between small globular bodies in cells and those which form precipitates? Has it ever been observed, that a precipitate is formed from a nucleolus, as has been found in cells? Or is a precipitate a vesicle filled with a liquid? Here analogy is entirely wanting; and all that we can say is, that nucleoli appear to have a globular form in common with the smallest molecules of many precipitates. Such a conformity, indeed, ought not to lead us to any other conclusion than this, that the general laws of attraction are applicable to small molecular groups,—whether organic or inorganic. But it is just because those laws are general, that they are insufficient to explain a peculiar series of phenomena, or of differences between animate and inanimate bodies.

I am convinced that a knowledge of the way in which precipitates are produced, does not give us the least assistance in explaining the production of a cellular membrane. True it is that, when the cell-walls are burned, inorganic substances, such as silica, lime, and potash, are left behind. But I think it wrong to conclude from this, that there is any analogy between the cell-wall and a precipitate. Inorganic substances are constituents of tissues as well as organic substances. Cellulose occurs very rarely in plants entirely free from inorganic constituents, with which it is in chemical combination. With these it forms one chemical substance. Cellulose and lime, for example, produce one body. When, therefore, the carbon, hydrogen, and oxygen are volatilised, the lime, &c., must of necessity remain behind.

I am of opinion, that in attempting to explain the production of elementary parts in the organic kingdom, we must have recourse to the idea of activity or function; otherwise, the explanation will remain defective. This idea of activity or function is embodied in the idea of carbon, hydrogen, nitrogen, and oxygen, as conveyed to us by the organic groups, which are in a continual tendency to become chemically changed, and which actually are constantly undergoing such

change. The very smallest molecule which combines with others, and forms a nucleolus, is a little organ, for it performs a function. It possesses the power of generation, and is in that sense an individual; not simply a molecule, but an active molecule. In this respect it differs from a precipitate, which is united into a granular body by a mere cohesion of its particles, without manifesting any other activity.

This activity—vital action we call it—proceeds from these four altogether peculiar elementary substances, carbon, hydrogen, nitrogen, and oxygen, as soon as their combinations are placed in certain peculiar conditions. These conditions, though entirely of the chemical class, are different, however, from those which are usually termed chemical, inasmuch as they either cannot be, or are with difficulty, established by art. The first product in these special circumstances is the formation of peculiar combinations, which assume peculiar forms, and exhibit a certain permanent activity as long as they are under the same circumstances. If, therefore, in the hypothesis mentioned above, we change the word precipitation into peculiar chemical arrangement, with a development of activity in the new bodies, and of new forms resulting from the action of the composing elements, then we consider this as a definition which is unobjectionable.

I believe we might define life and its functions in a few words, as being the chemical relations of carbon, hydrogen, nitrogen, and oxygen, with all their results; though there are many vital actions which cannot yet be explained according to this definition. For further particulars on this subject, I refer to the first chapter; but I considered myself obliged to develope here somewhat more in detail the production of elementary forms. It is nothing else than chemical action; but this is by no means sufficient to identify it with precipitation. The reduction of iron in a blast-furnace is a chemical action, and so is the combustion of combustible bodies, but neither of them is a precipitation.

D. Of the Inorganic Substances in the Organic Kingdom.

It has been observed that, in the combustion of vegetable

organs, after all the organic substances have been decomposed, an ash is left behind, which exhibits a real skeleton of the organ. Goeppert found this skeleton to consist of potash and lime,* but other bases must also be present. In many plants silica may thus be found, which,—when, for instance, cells are burned,—shows the exact form of the cells in the fine spongy ash, that remains behind. This silicic acid is introduced into the plant in the form of silicate of potash, from which some vegetable acid, combining with the potash, has separated the silicic acid. The new potash compound is dissolved in the sap of the plant and transferred to some other place. The forms of the sponge-ash differ with the kind of organ that is burned—from spiral vessels, for instance, the ash obtained is sometimes very beautifully twisted in the spiral form. Most of these inorganic substances may, to a great extent at least, be extracted by certain solvents; the silicic acid by means of potash, and the bases by hydrochloric acid.

Botanists have not yet decided whether these inorganic bases, salts, and acids, are to be considered as component parts of the organ, or as mere internal deposits. The former opinion is maintained by Morren and Reade.†

The matter is now ripe for a decision.

Cellular systems can exist without even the smallest trace of inorganic constituents, as is shown in various mould-plants. Not a trace of ash is to be found in the Mycoderma vini, for instance.‡ Moulds, which I saw produced in large quantities from milk-sugar, contained not a trace of ash. The inorganic constituents of plants, therefore, are not indispensable to the formation of cellular plants.

If, on the other hand, we bear in mind that the same inorganic constituents are found in so many different plants, then the conclusion is natural, that these constituents perform some function within the plant, and are not merely accidentally present there.

* Poggendorff's Annalen, Bd., 38, S. 568.
† London and Edinburgh Phil. Mag., Nov. 1837, p. 413.
‡ Scheik. Onderz., Deel. 1, p. 539.

1° This, however, is not the case with all the inorganic substances that are found in plants. The silica, carbonate of lime, or other precipitates deposited in the cells, are in a passive condition, and have been produced in a passive manner. They exactly resemble those precipitates which have been produced without the aid of organic bodies, and are formed in a similar manner, viz., by the addition of a certain dissolved substance to the liquid within a cell, holding another solid substance in solution with which the former can produce a precipitate. If, for instance, silicate of potash in a vegetable sap is mixed with an organic acid, such as oxalic acid, oxalate of potash and silicic acid must be formed. A great number of substances are thus separated upon and in the cell-walls; for into these walls, saturated as they are with saline solutions, other liquids often enter which can produce precipitates with those substances which they contain, and these precipitates may be deposited in the minute cavities of the walls. How this is accomplished, may be conceived by imagining a piece of paper moistened first with chloride of calcium, and then with carbonate of soda. Between the fibres of the paper chloride of calcium was enclosed—to this carbonate of soda is added, and hence a precipitate of carbonate of lime must be deposited between these fibres.

In this manner various salts, which are insoluble in water, but which exist in the parts of animals and vegetables, have been deposited there. They continue in the place where they have been first separated, unless some liquid capable of dissolving them be afterwards introduced; an acid, for instance, which can remove the precipitates from the cell-walls, just as hydrochloric acid, used to purify filtering paper, can dissolve the carbonate of lime, carbonate of magnesia, phosphate of lime, oxide of iron, &c., which are enclosed between the fibres of the paper. But there are only some plants through which such acid liquids circulate. Many vegetable juices are devoid of any free acid, and if, therefore, in these plants such a precipitate is formed, it cannot be again dissolved.

Payen* has observed such precipitates in many plants;

* Comptes Rendus, II. p. 401, 1840.

frequently, for instance, in some species of Ficus, F. ferruginea, laurifolia, &c. They present themselves as clavate little bodies, covered with a lime-like precipitate; he saw them of a large size in Parietaria lusitanica and arborea. In Celtis Australis their form was cylindrical. They are chiefly found on the superior surface, below the epidermis. A large leaf of Broussonetia papyrifera contained 134,000 of these bodies. According to Payen, carbonate of lime is often found between the cells of the parenchyme of the leaves and their nerves, in the petals and stems.

This carbonate of lime is often found in plants, of which the sap is so acid, that, when it comes in contact with the carbonate, carbonic acid ought to be disengaged. Payen thinks, that in such cases the precipitate has been produced by the carbonate of ammonia of the atmosphere; this, however, is not likely.

The crystals of silica, with which the cells of the Gramineæ, Characeæ, and Equisetaceæ, are filled, exist, according to Payen, on the surface of many, perhaps of all, leaves. Occasionally he found them also in the intercellular canals, in the form of spheroïdal concretions. The cell-walls of the epidermis in all plants are regularly incrusted with silica, but it is found also in the interior cells, though it occurs there much less frequently. We are, as yet, entirely ignorant as to the functions performed by this silica.

Chara translucens has a covering of silicic acid, whilst Chara vulgaris, under the same circumstances, has one composed of silicic acid and carbonate of lime, and Chara hispida has a covering of carbonate of lime only.*

There are many constituents of the animal body, especially the salts of the bones, of the teeth, &c., which are in the same condition as the inorganic constituents of plants just mentioned. They are deposited in such a manner that they are easily accessible to liquids. They can be readily removed by artificial means. The lime-salts may be removed from bones, teeth, ivory, &c., by digesting them with hydrochloric

* See further, Payen in Mémoires sur les Développemens des Végétaux, p. 313.

acid. In some diseases, such as Rhachitis, &c., in which softening of the bones occurs, the bone-salts, previously deposited, are again dissolved and removed. This can only be effected by some acid liquid. As the blood is naturally alkaline, it cannot dissolve these salts, and as in Rhachitis the salts disappear from the bones, it is evident that in this disease the blood must have undergone real chemical changes, and that this nourishing fluid, as it comes out of the bones, must be acid, or at least able to dissolve salts of lime.

Osseous tumors and similar excrescences are instances of a morbid secretion of these lime-salts, of their deposition in places where they ought not to be; while exostose results from an expansion of the tissue, in which the bone-salts are usually deposited.

The shells of crustacea, and of tortoises, as well as many other animal products, originate in a similar manner.

Besides this passive deposition of insoluble inorganic substances, there is an active deposition also, being a chemical combination of these substances with the organic parts of the tissues, so that they become constituent parts of the tissues themselves. A multitude of instances of this kind occur, especially in the animal kingdom. Even from the fibrin of the blood, or from coagulated albumen, the inorganic substances cannot be entirely removed by an acid.

2° If this combination is so intimate in substances which have been originally in a state of solution, it must be much more intimate still in substances that are naturally solid. Thus the ligamentary tissue contains a large proportion of carbonate and phosphate of lime; in chondrine a still larger quantity is present; in a word, these compounds are found chemically combined in all animal substances, in all classes of tissues. Into the corpuscles of the blood, they have so deeply penetrated, so completely combined with the cellular membrane, that, after this membrane is burned, they remain behind, having the same form as the corpuscle of the blood itself.*

* Mixed with them, are, however, the salts of the serum, with which the blood corpuscles are thoroughly saturated.

It is not very difficult to say by what force the inorganic substances, in the cases mentioned, are united to the organic parts; why, for instance, in the wall of a young cell, consisting of cellulose, or in a spiral vessel, inorganic substances are deposited. The force is no doubt identical with that by which metallic oxides, such as oxide of iron, alumina, &c. adhere to substances in the process of dyeing cotton and other tissues. But no satisfactory explanation has yet been given of the nature of this attraction. Bergmann, Macquer, and Berthollet considered the latter combinations as chemical; others compare them to the retaining of metallic salts or colouring matters and gases by charcoal and other porous substances, and therefore consider them as effects of attraction at minute distances, without regard to equivalent proportions.*

All that can be stated on this subject with certainty is, that no substance is known to exist in the organic kingdom which is perfectly neutral, that is, which has no power whatever of combining with other substances. The cellulose, which is the chief material of the young cells in plants, is certainly not a perfectly neutral substance; on the contrary, it possesses the power of forming chemical combinations with lime, potash, magnesia, and oxide of iron. If the formula for cellulose be correct, viz., $C^{24} H^{21} O^{21}$, the proportion of inorganic base, which unites with cellulose into a neutral compound, might contain a quantity of oxygen equal to a 1-21st part of that of the cellulose.

Instead, therefore, of being surprised that the cell-wall contains inorganic bases, we ought to wonder that the quantity which it does contain is not larger. In many cells the separation of bases is prevented by their not being in a free state; the acid, which in the sap is in combination with the base, prevents the saturation of cellulose by lime, potash, &c. Wherever, therefore, a constituent of the cell-wall itself has the character of an acid, such as mucilage or pectose,†

* See Crum. in Journ. für Pract. Chemie, 1844, No. 11 and 12, S. 164.

† Pectose is the name given provisionally to the substance, which, when boiled with an alkali, produces pectic acid.

the wall is found to contain a large proportion of bases, which cannot be extracted from it by weak acids.

The source of all these inorganic substances that are present in plants, is the vegetable sap which is sucked in by the roots. Animals receive them either from plants or from the animals upon which they live, and also from water. The greater part of the salts that exist in the serum, are found in common water (p. 124): and from it the salts are derived, which are necessary to the formation of tissues and of the precipitates above mentioned. Phosphate of lime, which is not contained in common water, and oxide of iron, are supplied to animals by plants. A large quantity of the former exists in corn crops, and, according to Raspail,* in a crystallised state in the Orchis, Ornithogalum, Narcissus, Hyacinthus, &c.

In a former note, p. 244, I gave an abstract of some recent experiments of Chodnew, on pectin and pectic acid, which has led him to pronounce the previous researches of Mulder, Regnault, Fremy, and others, to be erroneous, and to establish a series of five different compounds, according to him either existing in, or easily obtained from, the common turnip. In giving this abstract, I stated, at the same time, my conviction, that whosoever should again take up the subject would arrive at results very different from those of Chodnew. The more recent investigations of Mulder have confirmed this anticipation, and have presented a very striking illustration of the haste, and of the want of care and skill, with which the young chemists of the present day are pushing forward the branch of organic chemistry.

Mulder has shown that of all the five compounds described and analysed by Chodnew, *only one exists*, the formerly well-known and long described *pectic acid*. All the other substances he analysed were mere mixtures of cellulose, sugar, dextrin, protein compounds, and pectic acid, in various states and proportions.

One important correction, however, these new researches have induced Mulder to make on the formula for *pectic acid*. He finds that as it is extracted from the turnip in a free state, it contains water in a state of chemical combination, that it is best represented by the formula :—

Pectic acid, (free)	...	...	$C^{14} H^{9} O^{12} + H O$
Pectic acid in its salts,	...	...	$C^{14} H^{9} O^{12}$

For so much knowledge we are indebted to Chodnew.

Pectic acid is extracted from the turnip by grating, washing well, then boiling in dilute carbonate of soda, and precipitating the filtered solution. To the *unknown* substance in the turnip, which by boiling with an alkali, is then converted into pectic acid, the name of *pectose* is provisionally given.—*J.*

* Chimie Organ., Paris, 1838, tome 3, p. 597.

This salt must be present in a state of solution in the blood of animals. Being first dissolved by the hydrochloric acid in the stomach, it would be precipitated again in the blood, which is alkaline, were it not that the phosphate of lime can form soluble combinations with the soluble albumen and fibrin.* It circulates through plants in the same manner as through the animal body, viz., united with protein into a soluble compound. There also the soluble albumen is the vehicle of this insoluble salt, and hence it is likely that in the seeds of the corn crops, which contain so much coagulated albumen in combination with phosphate of lime, it has been introduced as a liquid into the very places where it is found.

We can very well imagine how plants take up these insoluble salts from the soil. The latter contains free acids, chiefly acetic acid, formic acid, and the several organic acids peculiar to the soil (p. 146). By them lime and magnesia, phosphate of lime, and oxide of iron, are dissolved; and the weak acid liquid thus produced is carried on to those places in the extremities of the roots where protein is prepared. It is from that place, at least in part, that by means of the protein these bases and the phosphate of lime are carried along. The same process takes place in animals. The phosphate of lime, for instance, contained in grain, is dissolved by the hydrochloric acid in the stomach, and converted into a soluble salt of lime. This, however, is not transferred into the blood unchanged, but the acid fluid being made neutral by the alkali, present in the small intestines, the lime-salt would be precipitated, were not protein present, by which the salt can be taken up, and transferred into the blood, and through the blood into every part of the body.

But it is less easy to explain how the phosphate and carbonate of lime are separated from the blood, and deposited in the bones. It is probable that this is connected with the transformation of those constituents of the blood, by

* We shall show, when treating of the blood, that Enderlin's experiments (Annal. der Pharmacie und Chemie, Maart, 1844, S. 317,) are incorrect. He concludes from them, that the salts in the blood consist chiefly of phosphate of soda.

which this salt is held in solution, into the gelatinous tissue of the bones.

If the gelatinous matter of the bones is produced from decomposed fibrin, or from tri-oxide of protein, which is produced from fibrin by respiration, (for this tri-oxide has also the property of combining with phosphate of lime) then the phosphate and carbonate of lime, present in fibrin, &c., may be left behind in the form of precipitates at the place where the transformation takes place, and thus the little cavities, left open by the gelatinous tissue, may be filled up. If this is the nature of the process which takes place, then it is evident that the lime precipitated in the skin, the serous membranes, and other parts produced from gelatinous tissues, must be redissolved, as the quantity of lime-salts which are found in these parts is not large. This may be explained by the plethoric state of the skin, and the activity of the serous membranes, which are continually secreting fluids; whilst the slowness with which the blood circulates in the bones, causes the lime-salts, once deposited, to remain on the spot where they are secreted.

It is certain that the inorganic substances in the fluids of the animal body are combined in equivalents with the organic substances present in the same fluids. The fibrin of the blood, when separated in a pure state, contains a proportion of salts, which is constant for the same species of animals; so the crystalline of the eye always contains 0.6 per cent. of a white ash, in which lime is found. This may, therefore, be considered as an established fact with regard to every elementary tissue. In some constituents of plants, both solid and liquid, this must necessarily be so. Cream of tartar exists in grapes in the state of tartrate of potash, plus tartrate of water; mixed, however, with tartrate of lime in the state of a neutral salt. That, however, the quantity of oxygen contained in all the bases of a *whole* plant, should be constant for the whole species of that plant, as Liebig asserts, is evidently impossible. (See *Inorganic food of plants.*) This is to be considered equally impossible, as that the quantity of oxygen contained in all the bases, which are present in every individual of the same species of animals, could be constant.

It is remarkable that, within certain limits, the inorganic constitution of plants may vary with the soil, from which the plants obtain their salts. Some of these constituents, however, cannot be replaced by others, and if they are deficient in a soil, the plants get into a languid state, or even do not grow in it at all. We shall enter into this more fully when treating of the nutrition of plants. All that is required here, is to mention generally, in what state the inorganic constituents exist in the elementary tissues of plants and animals: we call this an ordinary chemical state or condition. The bases,—such as lime, soda, potash, magnesia,—neutralise the solid constituents of the tissues, which have, in most cases, a high equivalent weight, provided this be not prevented by other causes. In many tissues the bases are replaced by basic salts. The reason why animal tissues contain a larger proportion of inorganic constituents than those of plants, is that the fluid which circulates in animals is alkaline. Among the vehicles by means of which these bases are transferred from one place to another, are—in plants and animals, albumen,—in plants alone, dextrin and mucilage,—in animals alone, tri-oxide of protein, and dissolved albumen and fibrin.

The observations made by Meyen, that under the epidermis of fig-tree leaves, crystalline substances are found, hanging, as it were, from a cellular string within larger cavities (utriculi), have induced Payen* to institute a great number of investigations into the crystalline substances of plants. He has met them in many Urticeæ, and various other plants. According to him, these crystals are formed by an organic tissue, which at the same time secretes the crystalline substance, and becomes converted into the cavity in which this substance is inclosed. The little organ by which the crystal is secreted, is placed in the centre of a large utricle. It consists of two parts, different both in structure and in function; the one is formed from the tissue of the surrounding cells, and constitutes the cellular string

* Annales des Sc. Nat., Dec. 1841, p. 321.

of which one end is fixed into the interior part of the epidermis; the other end consists of cells so small that it has the appearance of being composed of little points aggregated into one mass, which, as Payen states, are like a lustre hanging by a string in the utricle. This apparatus does not undergo any change during the growth, but the little vessels (vascuoles) are gradually filled with a solution of carbonate of lime, from which this salt is crystallised out, so that mamillar or crystalline particles appear on the exterior surface of the cellular layers. In other plants, however, this secreting organ is sometimes of another form, as for instance, in Broussonetia papyrifera (p. 386).

This induces Payen to conclude that the crystals in plants are not deposited by chance, but are produced by peculiar organs. This conclusion is certainly much too general; for the immense number of crystals of oxalate of lime, which are found loose in the cells of so many plants, can not require peculiar organs for their production, although they are of great importance as regards the physiology of plants, since they show the transition of carbonic into oxalic acid, with disengagement of oxygen:

$$C^2 O^4 = C^2 O^3 + O.$$

Payen has found the oxalate of lime under different forms. These were either needle-shaped crystals, radiating from a common centre, and placed in the parenchyma and around the nerves of the leaves of various plants, or rhombohedrons aggregated into a large volume, as for instance, in the parenchyma of the leaves and below the epidermis of Citrus, Limonia, and Juglans regia. He found much of this salt, and in large masses, in the Cacteæ, where it had the form either of sharp laminæ or of prisms, more or less elongated, which by their union formed spheroids that were either rough or without sharp points. He found similar crystals of this salt in plants related to the above, such as Opuntia, Echinocactus, Cereus, Cactus, Rhipsalis.

In the biforines of Turpin also, Payen discovered two little crystals of oxalate of lime, so placed that when the needle-

shaped crystals are dissolved out, the membranaceous utricle in which they are enclosed becomes quite flexible.

When the little organs containing the crystals of oxalate of lime were burned, Payen found that a siliceous substance was left behind, which had retained exactly the form of the organ by which the salt was secreted. This induced him to burn fragments of the stems of Gramineæ and Cactus, and also parts of the leaves, the petals, and the pollen, having previously digested them with acids; and he always found those siliceous remains in such a form, that they still represented even the most minute peculiarities of the organisation, having sometimes irregular masses of silica intermixed.

The little organ by which these crystals are secreted is not cellulose, but, as it is called by Mirbel, (the reporter of Payen's labours) *cambium globulo-celluleux*. Now, according to Payen, cambium contains a great deal of nitrogen, and so in the parts which contain the crystals, though consisting of cellulose, nitrogen is found, in consequence of the secreting organ being built up of cambium.

Payen thinks that the secretion of oxalate of lime is owing to the juices being either neutral or alkaline. The clear, colourless sap of Mesembryanthemum crystallinum has an alkaline reaction, whilst that of the tissue surrounding the vesicles, which are filled with liquid, is acid. Owing, therefore, to the alkaline character of the liquid *within* the vesicles, the oxalate of lime, first held in the solution, can be crystallised out, which actually takes place.*

This secretion by peculiar organs is, in our opinion, dependent upon the general causes of change of materials, which are active in plants. It is an established fact, that carbonic acid is decomposed in plants. This carbonic acid is not decomposed by *organs*, but by substances in activity, and therefore necessarily in a state of solution. At the formation of oxalate of lime, these substances may be enclosed in peculiar little vesicles; but these minute cavities are only the spaces *in*

* See Payen in Mémoires sur les Développemens des Végétaux, 5e Mémoire, p. 287.

which, and not the agents *by which*, the change is accomplished. In order to give any account of the changes which take place in the chemical nature of organic bodies, we must attempt to analyse the idea of an organ, and so to reduce it to its simplest signification. (See hereafter the section on *Conversion of Substances in Plants and Animals.*)

Unger* has published a number of observations on the crystals found in plants. From Piper blandum, Ficus bengalensis, and Marantha zebrina, he has obtained crystals, consisting of an organic acid and lime; in the two latter plants this acid was oxalic acid, but the nature of that in the former he could not determine.†

All animal fluids, of whatever description,—blood, lymph, saliva, urine, bile, &c.,—always hold crystallisable substances in solution. But in animals both the large quantity of the dissolving liquid, and the rapid circulation of the fluids—which goes on without interruption in most parts of the organism—prevent the deposition of those substances. In plants, on the contrary, it is materially assisted by opposite causes. As long, therefore, as the animal body is in a normal state, no crystals or deposited inorganic substances are found in it, except only in the bones and the adjoining tissues, where the slower passage of the nutritive fluid acts as the chief cause of the deposition of lime salts. Similar secretions are also to be seen in the formation of the testaceous teguments of some animals, such as the shells of snails, muscles, and oysters, the development of the calcareous shells of eggs, and in other similar cases.‡

In none of these organs could a deposition of the solid substances take place, any more than in the muscles and similar tissues, if the fluids circulated through them as quickly, incessantly, and largely, as they do through the latter. Nay, if the fluids passed through quickly and abundantly, such solid parts, although actually deposited, would be re-dissolved and carried off.

* Annalen des Wiener Museums, Bd. 2, S. 1.

† See also Meyen's Physiology, I. S. 212.

‡ See further, Valentin in Wagner's Handwörterb., I. S. 636.

Such is the general exposition of this process so far as science can give it at present. We shall enter into further particulars upon this subject when the tissues are treated of separately.

From what has been stated, it is evident why the crystallisation of solid substances occurs so frequently in plants, but so rarely in animals.

Precipitates in the organic kingdom, when produced from a large quantity of liquid, make their appearance in the animal body chiefly under the form of diseased excretions. Many of the concretions which are present in these, are highly important. Bezoar and horse-stones are produced in the intestines; the biliary calculi in the biliary canals; gravel and stone—a precipitate or a crystalline concretion—in the urinary organs; solid calcareous concretions in the inner part of the ear, and in the salivary canals; ossifications in the rib-cartilages and the coats of the arteries; solid deposits in tissues, which are usually free from them, such as occur in the ovaries and in the case of gout.

The general cause of the formation of these precipitates is, that the liquid contains one or more solid substances in larger quantity than it can hold in solution; in the bile, for instance, cholesterin, and in the urine oxalate of lime, urate of lime, and uric acid. If the substances present are such that they can produce precipitates in the urine, gravel is formed; if, on the contrary, they can only deposit themselves slowly, an ordinary crystallisation takes place, which is erroneously supposed always to originate around a little flock of mucus or a foreign nucleus. An ordinary crystal does not require a foreign nucleus for its production; neither is this required by uric acid, which, if present in large quantities, has a tendency to crystallise in the animal body.

Both the first production and the increase in size of these solid bodies, are effected by one and the same cause. From the excess of solid substances a tendency arises to form a small crystal, and subsequently to make this grow to a larger size. The production of such concretions is an action in which the organism takes no direct part; it

is to be classed with ordinary precipitation or crystallisation. The stones in the intestines of horses are formed from the salts of their food; the bezoars, which contain lithofellinic acid, from a product of the bile.*

E. The Tissues of Plants.

A small number of tissues has sufficed for the production of the vegetable kingdom, with all its variety in external form, with all the multitude of members of which it consists. The main organs of this kingdom are cells, of whose origin and structure we have just treated;—membranaceous little bags, which, though placed near each other in different ways, and united into new and different forms, always constitute the great bulk of the plant.

We have remarked before, that a plant may consist of one single cell. Some mould plants consist of a few cells, united into a whole. The more complicated this union is, the more numerous are the functions which the little plants can perform, and the more their external forms are varied. In proportion to the diversity of the organs, developed from the cells, the functions and forms become more diversified; hence the investigation of the tissues of plants is nothing else than the investigation of the position, form, connexion, and transformations of the cells in plants.

The cells of plants present some points of similarity with those of animals, but at the same time they are characterised by important differences. The most essential point of similarity is, undoubtedly, the independence of their existence and action.

But the differences between vegetable and animal cells are as great as the difference of the orders of beings to which they respectively belong. A vegetable cell cannot produce an animal tissue, neither can an animal cell give rise to a vegetable

* Guibourt, in Comptes Rendus, tome 16, p. 130. Berzelius, Jahresb. 1843, S. 670. I do nothing more than refer to this subject in passing, because it is connected with general chemical laws, and not with those special rules which operate in the organic kingdom.

one. The substances from which the former cells are built up, are entirely different from those of the latter. In not one animal cell has even a trace ever been found of that substance which constitutes the whole of an unincrusted vegetable cell, viz., cellulose. The latter being in all plants, without exception, the material of the original cells, is the cause of the similarity in the structure and functions of plants; and its absence in animals is the cause of the difference between vegetable and animal cells. However cells may be changed by age, the cellulose never entirely disappears, though other substances are often deposited upon it.

Another remarkable difference between the cells of plants and those of animals is, that the former have a great tendency to preserve—the latter to lose—the cellular form. With the exception of the different kinds of epithelium, feathers, cartilaginous tissue, and a few other substances, the animal tissues, when full grown, always consist of transformed cells or other original particles, produced from cell kernels. These particles have often retained nothing of what they were during their development, except the cell kernel or nucleus, and sometimes not even this; whilst, on the other hand, the great mass of plants, both vascular and cellular, continues to consist of real cells, of which only the walls increase in thickness. Even those parts which are called vessels by botanists,—with the exception of the laticiferous and the spiral vessels,—are nothing but a kind of elongated cells, and to them, therefore, the name of cells is equally applicable.

There still rests, alas! a thick cloud over our knowledge of the cells of plants, although the most acute philosophers have, with the greatest exertion, directed their attention to the subject. Different cellular systems, though similar in form, though apparently of the same chemical composition, though drawing their food from the same source, produce very different substances. In general the greatest conformity prevails in regard to the cells of plants, notwithstanding the variety in the form and substance of their products. One universal substance, cellulose, exists in *all* plants, constituting the basis, the material of their cells. But this very fact, that

one single substance can assume the most different forms, prevents us as yet from giving any satisfactory exposition of this part of natural science.

F. The Connecting Substance of the Cells.

It has long been a matter of uncertainty how the connection between the cells and other simple organs in plants is established. If we assume a cell formation, by and from the cells, either in the sense of Schleiden and Schwann, or in that of Mirbel, or in any other sense, this point—the means by which the cells are connected together—is left entirely undecided. The juxtaposition of two hollow membranaceous little spheres does not imply their intimate connexion,—does not enable them to form a tissue.

Besides the point of mere cohesion, there is another still requiring elucidation, viz.: do the cell walls cohere directly, or is there a substance between them, by which the walls are bound together?

According to Mohl, the composing simple organs are connected together, not directly, but by means of a peculiar substance, which he calls *intercellular matter*. In many plants, especially in the Fuci, the cells are at such a distance that their walls cannot possibly touch each other; and, therefore, if there were no substance between them, an empty space ought to exist. The substance found between these cells is called by Mohl, intercellular matter.

In plants, where the cells are at a great distance from each other, this matter of Mohl's must constitute a large portion of their bulk. But in most plants this great distance does not exist. Hence we might expect that in plants, where the cells and vessels are in direct mutual contact, this intercellular matter should be wanting. But it has been found even there;—the means employed being nitric acid, by which the substance between the cells was dissolved out without the cells themselves being in the least affected.

Both the character and the mode of production of this substance are as yet unknown.

In the investigations which I have made, along with

my colleague Harting (see below), we have very often observed traces of an intercellular matter. In the seeds of Iris, fig. 82, and those of Phytelephas, fig. 85, the cells, when acted upon by strong sulphuric acid, are immediately detached from each other, whilst a transparent margin is left between them, which can only be accounted for by supposing the presence of an intercellular matter, which has been dissolved. The same took place in various other instances, as may be seen in the plates. We do not yet, however, consider ourselves entitled positively to assume the existence of a general intercellular substance. In by far the greater part of our investigations we found it absent.

Among the substances that are to be considered as intercellular, or at least, serving as a boundary between the walls of young cells, we may include pectose. This substance partly penetrates into the cell-wall itself, but in part it separates the cells from each other, as in turnips, forming the external layer around the cellulose. We observed the same in the collenchyma of some plants (see *Collenchyma*).

G. Vegetable Cells.

These cells assume different forms according to their mode of growth. They are globular if not acted upon by extraneous causes, and if the substance of which they consist is uniformly distributed over them. They exist in this condition in young parts, and in the merenchyma of herbaceous plants.

If developed in large quantities, and continually increasing in bulk, they press against each other; and when all are of the same size they must necessarily be compressed into a regular dodecahedron, as a sphere can only be in contact with twelve others at a time. Such cells are frequently met with, though not perfectly regular in form.

They also assume different forms according to the manner in which they are nourished, and in consequence of their being elongated. We are unacquainted with the causes of this difference of nutrition or of this elongation, but we see the

final results of these causes. Sometimes the increase in size takes place in two opposite directions, so that they become elliptical, and hence, by the compression of the adjoining cells, first elongated, and subsequently prismatic cells are formed. The cells of this description, when properly formed, are called elongated cells.

It is due simply to these two causes,—equal or unequal nutrition, and elongation of the cellular membrane, with or without pressure—that the cells in plants are very variable, not only as regards their own form, but also as regards the nature of the cell-wall, the forms of the parts which are built up from them, and even that of the entire plant itself. The similarity in external form exhibited by the same species shows, that a very great stability exists in the form of the cells of the same species; a fact, which science is still quite unable to explain. The membrane of young cells is homogeneous, at least no structure can be discovered in it. When it becomes older, however, it has almost always a very different appearance.

It is obvious that we must not take this homogeneity in the most limited chemical sense. We mean by it only that, so far as we can discover by the microscope, no difference can be perceived. There can be no doubt that, in a chemical sense, no cellular membrane is to be regarded as identical with another, unless it has completely the same form, and gives passage through its pores to exactly the same substances.

In young cells, the cell-walls are not to be considered as the most active parts of the plant, neither do these walls exercise by their material diversity so great an influence upon the fluids which pass through them, as to make them undergo a chemical change.

In general, too much importance has been attached to the presence of nitrogenous constituents in the *wall* of the young cells, consisting of cellulose. It appears from observations, which will be recorded afterwards, that frequently in young *cell-walls* not a trace of nitrogenous substances is to be found by which activity can be excited, but that they do occur in

the *contents* of young cells. In older *cell-walls* precisely the reverse is the case.*

This proves that the action cannot proceed from the *walls* of the young cells, and that the nitrogenous substances existing in the *contents* of young, and in the *walls* of old cells,—though both may be protein compounds,—cannot possibly be the same. Those in the *walls* of older cells seem to have passed into a state of greater fixedness; probably they have been changed into coagulated albumen, whilst those of the *contents* of younger cells, being in a soluble form, are to be considered as the main source of the change of materials which takes place in plants.†

The production of new substances, therefore, is performed within the membranaceous vesicles themselves; the cells themselves serve chiefly to separate and preserve the contained fluids. Into these innumerable little vesicles, filled when young with fluids of different kinds, in one place a new substance is introduced, or in another such a substance is secreted, and these are either deposited against the cell-wall, or remain as a part of the contents of the cell. We may, therefore, regard these innumerable little cavities, which are partly isolated, partly in mutual communication, as so many little pieces of chemical apparatus in which chemical operations are performed.

If, however, we considered the young cells as entirely passive, we should judge as erroneously, as if we were to consider them the first and last sources of vital action. They consist of active particles, although these particles are not the primary sources of action. That they are active, we learn, first, from their active manner of development, and secondly, from the transformations and incrustations upon their walls. These transformations do certainly proceed from substances which

* The word *cell-wall* is used here in a general sense, and the *primordial tissue* (schlauch) distinguished by Mohl, is at present not included in the phrase. The latter is a granular internal covering of the cell-wall—cellulose—which is contracted by the action of alcohol, and occurs very frequently in old and young cells.

† It is obvious that Payen has confounded the protein of the contents with that of the wall. (See p. 207.)

are present in the contents of the cells, yet they are subsequently performed also by the membrane, and consequently this membrane cannot be merely passive, but must react upon the contents.

While engaged in the observations which I have made in concert with Harting, I very often observed in this thin cell-wall an immense number of minute pores, which will be treated of afterwards. An account of these observations is given below.*

As the cells continue to increase in size, they cannot afterwards be nourished in the same manner as when they were of smaller dimensions, when the substances by which they are nourished were uniformly distributed over them. When the size has exceeded certain limits, the substance supplied by the cell-wall is distributed in a spiral form over the interior part of the cellular membrane. Of the cause, however, which induces the substance, deposited upon the membrane, to assume this form, we are as ignorant as of that which makes alum assume the form of an octohedron. These are things which are inexplicable at present by science; they are simply recognised as facts.

These spiral threads deposited in or on the walls of the cells are sometimes composed of a few convolutions only. If such a small set of convolutions is altered in growing, a ring

* The *apertures* which are rendered visible in the cell-wall, consisting of cellulose, by the reaction of iodine and sulphuric acid, have been most distinctly observed in the following plants. In the thin-walled medullary cells of Hoya carnosa; in the parenchymatic cells of Euphorbia caput-medusæ—in one cell, having a transverse diameter of 0.03777 millemetres, we counted 45 of these little holes,—in the pith of Asclepias syriaca they are large and oblong, and also in the very young cells of the wood, which still becomes blue by iodine and sulphuric acid;—in the parenchyma of Tradiscantia virginica; in the young parenchymatic cells of Cicas revoluta; in the young ligneous cells of Clematis vitalba; in the annulated cells of Opuntia microdasis. In Tradiscantia they had the size of 0.0005 to 0.0018 mm.; in very young leaves of Sempervivum arborescens, long before their period of development commenced, they had a size of from 0.0007 to 0.0014 mm. We also observed them in old and young medullary cells of Clematis vitalba. In an old leaf of Sempervivum they were the same size as in a very young one.

It follows from what is mentioned here, that what is stated concerning these pores being invisible (at p. 188 and 193) is now disproved as far as concerns the cells in which we observed them.

is produced in the cell-wall (*cellulæ annuliferæ*, annular cells), or several spiral threads are developed on the cell-wall, and unite with it in growing, forming an external net-work (*cellulæ retiferæ*, reticular cells). Sometimes the spirals which are spread out on the cell-wall take different directions at certain places, and if the cell now ceases to expand, the spiral disappears in growing, the deviating parts of it excepted (*cellulæ porosæ*, porous cells).* We shall presently consider more in detail the substance of which this spiral consists.

The cellular membranes of young or herbaceous plants are transparent, and in general colourless; but in some plants—for instance, in several mosses—they are saturated with a colouring matter.

In most cases, however, this colour of the cellular membrane is owing to the contents of the cell, which either penetrate the cell-wall, or simply show their colour through the thin membrane. A great many tissues, however, have their cell-walls incrusted, other substances being deposited either upon or within the walls, and so filling and expanding them. This matter by which the cell-walls are incrusted, may be very variable in its nature.

In many cells, of which the walls are incrusted, we observe several layers deposited one upon the other, which, with proper caution, may be separated from each other.

Some of these incrusted cell-walls, when boiled in water, become thinner, and are finally dissolved. Such are found in various lichens—in the Cetraria islandica, for instance—where the cell-walls are thickened by the amylaceous substance (Lichen starch) deposited *within* the membrane, without even a trace of true starch being present. The formula for this substance is $C^{12} H^{10} O^{10}$ (p. 217). This lichen starch, therefore, must be classed with the incrusting matters, viz., those of which the secondary cell-walls are formed; the primary cell-wall in the Lichen islandicus consisting of cellulose (p. 199).† The cell-

* Schleiden, Wiss Bot. I. p. 200.

† Fromberg (p. 199) found less hydrogen in the tissue of lichens when but imperfectly treated with alkali, than is found by Heldt. (Annalen der Chemie und Pharmacie, Bd. 38, S. 1.

walls in other plants, such as apples, become swollen and gelatinous by boiling, and then contain pectose; in others, such as Sphærococcus crispus, mucilage is present, of which the formula is $C^{24}H^{19}O^{19}$ (p. 239). Others, again, when acted upon by potash, grow thinner, and part with their ligneous matter, which, by the protracted action of the alkali, is changed into ulmic acid, the greater part of the cellulose being left behind. This is the case with all ligneous tissues (p. 198).

That part of the cellular membrane which is pure cellulose, is insoluble in water and almost insoluble in alkalies; it is decomposed by strong sulphuric acid, and if boiled with diluted sulphuric acid, is converted into dextrin.

H. The Primary Cell-walls.

A great number of physiologists have made observations upon the cell-walls of plants. Kützing* examined the Algæ, and found a single cell often to consist of several cells inclosed within one another; the wall of the common cell, therefore, having a number of layers equal to that of the whole of the inclosed cells. Hartig thinks† that the cell-wall is triple, consisting of three membranes deposited upon each other. The innermost is first developed, and the whole is surrounded by the outermost, except at those places where the cells touch each other. At the point of junction there is a membrane much thicker than either of the two others, which completely line the interior. He states that when a cell is first moistened with tincture of iodine, and then with sulphuric acid, the inner and outer walls are coloured yellow, and the intermediate one blue, the latter expanding very much, and even dissolving entirely, if strong acid be used. These observations of Hartig's have not been confirmed by ours. Cells with thin walls have only two layers, and those with thick walls, one, two, three, or four.

This subject has recently been more fully investigated by

* Physiologia Generalis.

† Beiträge zur Entwickelungs Geschichte der Pflanzen. Berlin, 1843.

Mohl.* In annual shoots of trees, or in stems of annual plants, he always found *within* the cell a separate wall or an interior membrane, which could be very well distinguished from the other part of the cell. It is a completely closed and thin-walled vesicle, and becomes very distinct when the part has been long preserved in alcohol, as it is then contracted, and is more or less loosened from the remainder of the cell-wall. By iodine it is coloured yellow or brown, and was generally present both in the mono- and di-cotyledenous plants which were examined by Mohl. It is also, and very rapidly, rendered visible by being acted upon for some minutes either by nitric or hydrochloric acid, subsequently saturated by ammonia, and coloured by iodine.

Mohl states that the nucleus, if still present, lies within this interior membrane. The surface of the membrane is not entirely smooth, but slightly granular. By the action first of iodine, and then of sulphuric acid, he states that it turns yellow, the remaining cell-wall becoming blue. By dilute sulphuric acid the first or interior membrane is neither changed in form nor dissolved. This membrane has been called by Mohl the *primordial-tissue*, and differs from what Hartig calls the interior membrane, or *ptychode*. Hartig means by this, the interior wall of the *full-grown* cell, and thinks that Mohl's primordial-schlauch has disappeared long before this period. It is Mohl's opinion that this *schlauch* or *tissue*, as the cell grows older, and as in consequence of this its wall is gradually incrusted with secondary layers, grows constantly thinner, and is slowly dissolved; being first either fixed to the cell-wall in the shape of a very thin granular tegument, or covering this wall as a net and no longer as a continuous membrane, and that it is finally completely dissolved and disappears. During the observations made by Harting and myself, we found, on the contrary, that though not always wanting in thin-walled cells, yet it was never present in young, and frequently not in old woody cells. Mohl thinks that in the latter cells the primordial-tissue begins to dis-

* Bot. Zeitung, April 12, 1844.

appear when the first traces of secondary layers are deposited.

It follows, from the experiments of Mohl, that this internal cell-membrane may exercise some influence upon the composition of cellulose, as found by analysis. The reaction of iodine and sulphuric acid clearly proves that the substance of this membrane is different from the exterior cell-wall; we cannot, however, as yet determine its precise composition.

Mohl further thinks that this internal membrane is present in every young cell, it being consequently produced along with the cell itself. It appears to him that it is produced by the nucleus (see p. 359), and that in its turn it originates the cellular membrane, properly so called, viz., that which is permanent and consists of cellulose. He does not, however, mention any direct observations on this subject.

Payen* often speaks of an internal membrane of the cell, which, when treated with iodine and sulphuric acid, does not turn blue or violet like cellulose, but yellow; and the latter colour he ascribes to the presence of a nitrogenous body. In fig. 10, pl. 1, he represents the section of a cotyledon of lint-seed, and in fig. 1, he gives that of the cells of Æschynomene paludosa, in which this membrane is reticular. It seems to be identical with Mohl's primordial-tissue. It is seen very distinctly in Aloe lingua, fig. 8, in the medullary cells of Tilia parvifolia, fig. 28, further in fig. 11, 16, 18, and several others represented below in the observations made by Harting and myself.

In the permanent cell-wall, according to Mohl, two parts are to be distinguished, the outermost of which he calls the oldest.† He thinks that many cellular membranes, though homogeneous in appearance, are not so, but exhibit distinctly several layers, when moistened either with sulphuric, nitric, or hydrochloric acid. He recommends that if the cells are soft, one of the two latter acids should be used; if they are more solid, the former. The blue colour produced in them by

* Mémoires sur les Développ. des Vegetaux, p. 211.

† Bot. Zeitung, April 26, 1844.

iodine and sulphuric acid, is, according to him, the effect of the action of the acid upon the substance of the cell-wall, and not that of the iodine, as Hartig thinks.

When secondary layers are present, Mohl thinks that the exterior cell-wall on which these are deposited must be the oldest, and that this, therefore, is also a sufficient contradiction to Hartig's observations. He finds an additional proof of these layers being really of secondary origin, in the fact, that in some plants they do not cover the whole cell-wall, being found in some parts of it only, as is the case in the Scotia. Consequently they must have been produced by certain more active spots of the cell-wall; spots, where we may imagine an apposition, similar to that which takes place in crystallisation, where homogeneous particles join together in a determinate direction.

As to the nature of the substance of which the *internal utricle** consists, we find that in the cells of the pith, and of the epidermis of the young stem of Phytolacca decandra, it is coloured yellow by nitric acid, after having been first separated from the interior of the cell and contracted into a much smaller diameter. Along with these internal utricles the nuclei appear very distinctly; some cells containing two, rarely three, while those which increase in number by means of partition-walls, have no nuclei. (P. 368.)

This internal utricle, therefore, is not only, like the nuclei, insoluble in nitric acid, but it is contracted by this and by other acids, and also by alcohol. It is rendered very distinct by the action both of sulphuric and hydrochloric acids, but best of all by that of nitric acid and alcohol. The yellow colour it assumes by the action of nitric acid, especially if ammonia is afterwards added,—whilst the nuclei remain colourless,—shows that it contains protein as a direct constituent, though this is not always certainly the case. (See Aloë lingua, fig. 8.) The change of colour effected by nitric acid in Phytolacca, however, proves to be not of such a nature as to justify us in considering protein as its chief constituent. Not a trace of cel-

* We consider this the best name for it, wishing to abstain from any decision about its origin.

lulose is found here, since by the action of iodine and sulphuric acid, no blue colour, the characteristic of cellulose, is produced.

We have, therefore, been able fully to confirm Mohl's observation of the presence of an internal utricle—of a membrane, which, through the action of the reagent mentioned above, quits the interior of the cell-wall, and is contracted, drawing the whole contents of the cell along with it. We have, however, been unable to determine—except in Phytolacca and a young Agave, where, we believe, we found the nucleus *within* the internal utricle—where the nucleus is to be found, whether in this internal utricle, or in the other part of the cell-wall. We have often observed it entire in very old cells, as we shall afterwards mention; and this has induced us not to call this utricle *primordial*. We found it both in thick and in thin-walled cells, in those with and without incrustation; and hence we doubt if the explanation given by Mohl with regard to that interior layer, be the right one. In some cases it contains nitrogenous substances, in others not even a perceptible trace. We are, therefore, as yet uncertain both as to its function and as to the nature of its substance. (Harting and Mulder.)

I. Cell-walls consisting of Cellulose.

Schleiden has (Poggend. Annalen, Bd. 42) recorded a property of young cellular membranes, which has lately been subjected by Liebig to a closer examination. (Ann. der Chemie und Pharmacie, Juni, 1842.) It is as follows:—When the membranes of young cells, after being soaked with tincture of iodine, are exposed for half a minute to the action of a mixture of 3 parts of sulphuric acid, and 1 part of water, a blue substance is produced, very similar to iodine starch, thus leading to the natural conclusion that the membrane has been converted into starch by the action of sulphuric acid.

This fact, that the membranes of young cells, when treated with sulphuric acid, acquire the property of being coloured blue by iodine, deserves our attention for several reasons

First, it affords an excellent means, in microscopical investigations of the organs of plants, of discovering differences which would otherwise entirely escape our observation. But it is especially in a chemical point of view that Schleiden's discovery must be noticed.

Chemists are not agreed as to the manner in which starch and iodine unite. Their combinations do not appear ordinarily to consist of equivalent proportions (p. 212). It is, however, not likely that the colouring of starch by iodine ought to be regarded as identical with the colouring of cotton or linen by madder, because there are a great many organic substances which take up iodine and are coloured brown by it, but none of them produces the colour which is peculiar to iodine starch. The colour of iodine, when in a state of division, is also very different from the dark blue colour of its compound with starch, if properly prepared. We must also bear in mind, that both a dry globule of starch and a very dilute solution of it, if mixed with iodine, are equally coloured blue.

I know only of two substances which are thus coloured by iodine,* viz., starch, and the young vegetable tissue, when acted upon by sulphuric acid. It is known that the Lichen islandicus contains starch,† and the jelly prepared from it may be said to be related to true starch, for when mixed with water and treated with iodine, the one part becomes blue and another brown.

The experiment recorded by Liebig (p. 308,) deserves particular consideration.

Ordinary sulphuric acid was poured upon cotton-wool, paper, and other substances, consisting of cellulose,—no wood was used, as will afterwards appear,—and the mixture was rapidly stirred. A transparent jelly was formed, to which water was added. A fine, white, floccy precipitate then separated, the liquid was filtered, and the residue was washed with water till all the acid had disappeared.

* I am decidedly of opinion that the tissues mentioned at p. 207, belong to the amylaceous tissues.

† Bulletin, 1838, p. 42.

Cotton wool was moistened with a weak tincture of iodine, and dried, and then treated with sulphuric acid in the same way. It became of a dark violet colour, the moment that the acid was added. When the gelatinous mass was mixed with water, a dark blue precipitate was formed. On filtering this, a brown transparent liquid ran through the filter. During the washing of what remained on the filter, this became gradually lighter in colour, and finally, it lost all its colour and all its iodine.

The substance which, in the first experiment, remained behind when cotton was treated with sulphuric acid and the product washed with water, did not turn blue when acted on by tincture of iodine alone. It could not, therefore, be starch. But if sulphuric acid was added, and then tincture of iodine, it again became blue. The same took place when it was first moistened with tincture of iodine, dried, and sulphuric acid then added. On the addition of water a blue precipitate was again produced in the liquid, and the substance on the filter became again colourless by washing. When put into ordinary sulphuric acid, it was again rendered gelatinous, as when it was produced the first time, but when treated with stronger sulphuric acid, it became soluble in water, and at the same time lost the property of being coloured blue by iodine.

With the view of ascertaining if this blue compound was only a mixture of very finely divided iodine with some gelatinous body, tincture of iodine in excess was added to acetate of alumina, and then a little carbonate of ammonia, so as to produce a precipitate,—the iodine remaining in excess. The precipitate, however, was not blue.

Tincture of iodine was also added to a solution of silicate of soda, and then a little hydrochloric acid, but the gelatinous precipitate of silicic acid was not coloured blue.

Considering these experiments in connection with what we remarked above, we are justified in concluding that the blue colour of iodine starch is not owing to a fine division of the iodine. The same conclusion is also come to by placing under the microscope a globule of starch, and letting it imbibe tincture of iodine,—at the same time recollecting

that other porous substances which may be procured in numbers from both the organic kingdoms, become brown under the action of iodine.

I cannot, therefore, coincide in the opinion expressed on this subject by Liebig in Geiger's Handbuch der Pharmacie; S. 1255. I think, on the contrary, that the cause which makes young cellular membranes turn blue by iodine, after being acted upon by sulphuric acid, is similar to that which produces the same colour in starch by means of iodine.

Now, the question is, whether the substance of the young membrane has been converted by sulphuric acid into starch? It is, as yet, impossible to give a positive answer in the affirmative; for after the acid is washed out, the substance ceases to produce this reaction, which, however, is exhibited by starch both in a granular and in a gelatinous state. When thoroughly washed with water, therefore, the substance is no longer starch. But is it starch *as long* as it is combined with sulphuric acid? I am disposed to answer this question in the affirmative on the following grounds. We ought first to bear in mind, that tincture of iodine alone is not sufficient to give a blue colour to young cellular membranes; that this colour is not produced on a subsequent addition of water; that it is not produced by the action of dilute sulphuric acid; that it appears only by the action of stronger acid (the bi-hydrate); and that if it be at all produced by still stronger acid, (the mono-hydrate,) it quickly disappears again, the cellulose being converted into dextrin. And if, finally, we take into consideration that starch is also converted into dextrin by sulphuric acid, then we think there are reasons which render it at least probable, that the membranes are really converted into starch at the moment that they become blue by the action of iodine and sulphuric acid. In other words, that the organic substance is really starch during its combination with sulphuric acid;—that the molecules of cellulose, whilst under the influence of sulphuric acid, do actually give off to the acid the half equivalent of water, by which their composition differs from that of starch ($C^{24} H^{21} O^{21} = 2C^{12} H^{10} O^{10} + H O$), in consequence of which the acid combines with more water:—that, however,

when an excess of water is added, and the cellulose is thus made to leave the acid, it takes back this half equivalent of water, to become reconverted either into cellulose or into a substance similar to it in composition.

Additional support is given to this view by the consideration that neither nitric nor hydrochloric acid have such effects upon cellular membranes coloured by iodine, whilst a completely saturated solution of phosphoric acid in water—of the consistency of syrup—acts in the same manner as the bi-hydrate of sulphuric acid.

We have endeavoured, by the following experiments, to ascertain more certainly the truth of this view; but they yield no positive results. We took a little cotton, which was left in ordinary sulphuric acid (the bi-hydrate), till it had become gelatinous—a proof of its having undergone the change before referred to,—and put it into absolute alcohol, by which it was washed free from sulphuric acid, without the access of watery vapours from the air. A little potato-starch was also converted into a jelly by sulphuric acid, and washed with absolute alcohol. The starch thus prepared was coloured blue by tincture of iodine, but the cotton was not.

Under these circumstances, however, it was possible that the substances might have again taken back the water, of which they had been deprived by the sulphuric acid, notwithstanding that the alcohol was completely anhydrous; for the acid contained two equivalents of water, and hence the substances had ample opportunity of resuming the water which they had lost.

We obtained the same result, however, by converting cotton into a jelly by means of sulphuric acid, and neutralizing the acid with powdered caustic lime. On now neutralizing the lime with an acid, and then adding tincture of iodine, we found that neither the water with which the substance had been washed, nor the insoluble part, was coloured blue. We did not, therefore, succeed in bringing the cotton, after the removal of the acid, into a state in which it could be coloured blue by iodine; and if it is really starch whilst in contact with sulphuric acid, this is, in some way or other, owing to a temporary transformation, by the acid, of the molecules of cellulose into starch.

The unchanged cotton (I.), and the colourless powdery product obtained from it by means of iodine and sulphuric acid, after being washed with water and digested with alcohol, (II.), had respectively the following composition :—

I. Cotton treated with alcohol,—

C	44.91
H	6.40
O	48.69

II. Cotton treated with iodine and sulphuric acid,—

C	44.30	44.46
H	6.20	6.19
O	49.50	49.34*

Their composition, therefore, is perfectly identical, and their properties being also the same, we are entitled to conclude, that after the action of sulphuric acid, the cellulose is reproduced by the addition of water.

If either the strength of the acid or the length of its action upon parts of plants, consisting of pure cellulose, be increased, dextrin is produced. This property adds to the probability that cellulose is temporarily converted into starch, as long as it is under the influence either of sulphuric or of phosphoric acid. Both the cellulose and the starch in plants are produced from dextrin (p. 201); and, therefore, as strong sulphuric acid can convert both starch and cellulose into dextrin, the idea that weaker sulphuric acid can convert cellulose into starch, is by no means paradoxical.

There is no reason whatever to ascribe the blue colour produced by iodine to its state of fine division; but the production of this colour is such a positive and decisive proof of the presence of cellulose, that we do not know of any more conclusive chemical reaction. Hence iodine and sulphuric acid afford, in vegetable organography and organogeny, excellent means for investigation, of which the value cannot be too highly estimated. To be satisfied of this, we need only glance at fig. 1. B.

* The full particulars of these, and all the other analyses recorded in this chapter, are given in Scheik. Onderzoekingen, Deel III.

representing a transverse section of an internode of Hoya Carnosa, in the state in which all its parts appear *under the influence of the same reagents*, iodine and sulphuric acid.

When tissues, consisting of cellulose,—such as the unincrusted organs of plants, the parenchymatic cells, &c.—are first soaked in tincture of iodine, dried, and then moistened with ordinary sulphuric acid, they always assume a fine blue colour. After a little while, however, the tissue is again decolorised, and this is especially the case when the acid begins to dissolve it and to convert it into dextrin. Hence when a stronger sulphuric acid—the mono-hydrate—is used, the blue colour appears either only for a moment, or even not at all. This again shows that the blue colour cannot be produced by a mere precipitation of iodine, but must be owing to a real combination of iodine with a new substance, which is formed under the influence of sulphuric acid.

This change of colour does not take place with every kind of vegetable tissue, as will sufficiently appear from experiments mentioned below. We ought, however, here to remark, that we invariably used a weak tincture of iodine, with which we moistened the substance once or twice, so as to soak it thoroughly with iodine, and then allowed it to dry in the air, and after that we wetted it with a few drops of the bi-hydrate of sulphuric acid. Wherever the mono-hydrate was used, it has always been expressly mentioned.

If the substance, after the moistening with tincture of iodine, be not dried before applying the acid, a crystalline precipitation of iodine takes place, by which any observation is made impossible.

This reaction of tincture of iodine and sulphuric acid on the vegetable tissues, is so general, that it deserves further consideration. It is distinctly produced not only in all young cell-walls, but in many older ones, such as the collenchymatic and merenchymatic tissues, and in all the unincrusted medullary cells; thus a very useful means is afforded for detecting cellulose. The reaction is even exhibited on cellulose, which has been exposed to the influence of powerful agents used to prepare and purify it. Flax, for instance, after hav-

ing been exposed to the action of chlorine; the seeds of Phytelephas treated in the same manner; the seeds of Cocos nucifera, treated with strong potash and chlorine; the seeds of Cocos lapidea, treated twice in the same way—all these exhibit the reaction of iodine and sulphuric acid with the same distinctness. Where we have not to do with pure cellulose,—for instance, in the internal layers of the fibrous cells of the bark (thick-walled prosenchymatical cells), or the spires of the spiral cells,—these two reagents have the greatest value, very far surpassing in efficacy every other we have tried. We have used them very frequently, and shall now proceed to treat particularly of the various species of cells, and to consider of what substances they seem to be composed. In this account especially, I need the reader's indulgence, as this is the first trial in this department of science; and I shall be obliged to refer to a series of particular reactions, fully to represent the facts that are connected with this branch of natural philosophy; facts which are still too isolated to be capable, in a scientific system, of being comprehended under any general views.

1° The *globular merenchymatical cells* in very young leaves of Agave Americana, when treated with strong nitric acid, become very much expanded. When nitric acid is used, diluted with an equal bulk of water, the cell-kernels which are visible in the natural state are very plainly seen (fig. 10). When exceedingly young they exhibit very distinctly the internal utricle with the nucleus in its wall; in some of them even two nuclei are seen.

Strong sulphuric acid dissolves these merenchymatical cells rapidly; when diluted with one-fourth of water it colours the cell-walls, previously moistened with iodine, blue (fig. 69); and the contents of the cell, brown.

These reactions show that the globular merenchymatical cells consist of pure cellulose. As the action of nitric acid does not perceptibly change the colour either of the cell-wall or of the nuclei, it follows that there exists in them either no protein compound at all, or this only in such a minute quantity that the xantho-proteic acid produced is imperceptible. If,

after the action of nitric acid, an excess of ammonia is added, not a trace of a yellow colour is produced; hence, we may safely conclude that these cell-walls contain no perceptible traces of protein.*

2° The *elliptic parenchymatical cells* of Aloë lingua are immediately dissolved by strong sulphuric acid.† By nitric acid the internal utricle is rendered very distinct in the form of a yellow granular membrane (fig. 8), the exterior cell-wall remaining unaltered. Not a trace of a nucleus is to be seen.‡ If an excess of ammonia is then added, neither the internal utricle nor the external cell-wall exhibit any change in appearance.§

By the action of iodine and sulphuric acid these cells become of a beautiful blue, and are readily dissolved. They dissolve very rapidly in strong phosphoric acid (of the consistency of syrup), and in strong sulphuric acid.‖

They are not perceptibly affected by aqua regia;¶ the internal utricle, however, is rendered very distinct; and the same effect is produced by strong hydrochloric, and diluted sulphuric acids. This shows apparently that this utricle is essentially different from the external cell-wall, which seems here also to consist entirely of cellulose, no admixture of any other substance being distinctly perceptible. The internal utricle is contracted by alcohol, hydrochloric acid, nitric acid, aqua regia, and diluted sulphuric acid; but as it is not co-

* When the action of iodine and diluted sulphuric acid (4 parts acid to 1 of water) has been continued for forty-eight hours, the whole is decolorised on the addition of ammonia, and the nuclei become distinctly visible, thus showing that they have not been altered by these reagents. Bromine, after some hours, renders the internal utricle of a very old Agave very distinctly visible. (Harting and Mulder.)

† And the chlorophyle contained in them turns blue.

‡ In the cells, which are situated close to the bundles of vessels, larg round bodies appear here and there (fig. 8, *c*) having a sharply defined edge, a granular appearance, and a yellow colour (globules of resin?)

§ The globular bodies referred to in the preceding note, assume a brownish tint.

‖ The globules of chlorophyle become blueish green, and are dissolved.

¶ Which, however, acts upon the chlorophyle, of which the globules become much smaller.

loured yellow or orange by nitric acid and ammonia, we have no reason to assume the presence of a protein compound here, any more than in the external cell-wall.

It is not entirely correct to say that this utricle disappears when the cells grow older; in Aloë lingua, at least, we always found it perfectly developed in the summit of an old leaf, where, therefore, it is a permanent membrane, as has likewise been stated by Mohl.

Both in the cell-walls and in the nuclei of young leaves not yet unfolded, no change is produced by iodine and dilute sulphuric acid. If, however, strong sulphuric acid is then added, these parenchymatic cells also turn blue. This also happens in those of old leaves on the application of phosphoric acid either preceded or followed by iodine. Both phosphoric and sulphuric acid, therefore, have the power of converting cellulose into the starch-like substance. (Harting and Mulder.)

3° *The angular parenchymatical cells* of Cicas revoluta, to be found at the base of a young petiole, exhibit on their transverse section a remarkable diversity in the substance of which the wall is composed. First, the large nuclei which are found in them are coloured yellow by iodine; whilst, by the subsequent application of diluted sulphuric acid, the thick walls turn blue, leaving triangular interstices. The wall presents spots which are alternately of a darker and a lighter blue, the exterior being much lighter than the interior layer of the same wall (fig. 27, *aa*). Close to the inside of this is placed a thin yellow membrane (internal utricle), (fig. 27, *b*).*

This angular parenchyme, therefore, contains not only cellulose but another substance besides, which is not converted into the starch-like substance by the agents above mentioned. This substance resists the action of stronger sulphuric acid without being even coloured by it; and although its character has not been more closely determined, it is certainly neither cellulose nor true ligneous matter. It may be pectose.

* In incrusted cells these walls have large pores; the interior wall is blue, the exterior brown, the former of which is seen shining through the pores (Harting and Mulder).

4° *The radiated or stellular parenchyma* may be beautifully seen in the partition-walls of the petiole of Musa Paradisiaca, and belongs to those tissues which consist of almost pure cellulose (fig. 9, A and B). It is not changed in colour by strong nitric acid, but it becomes somewhat inflated.*

When the cell-wall of the stellular parenchyma of Musa is itself exposed to the action of nitric acid, and then moistened with an excess of ammonia, it receives a slightly yellow tint, which indicates that it is not entirely devoid of protein. It is immediately rendered blue by the action of iodine and sulphuric acid (fig 9. A). From the colour being somewhat lighter blue, and from the swelling of the cell-walls under the influence of nitric acid, we learn that, although cellulose is the chief constituent of the cell-wall, yet it is mixed with some other substance which is not coloured by these reagents. This induces us to suppose that the cell-wall contains pectose.† The traces of protein in the cell-wall are accounted for by the presence of large quantities of coagulated albu-

* In several parts of the interior of the cells, thick, yellow, stellated bodies are to be seen (B, *aa*), which assume an intense orange colour when treated with an excess of ammonia, thus showing apparently—as they are inviaible, at least colourless, in the unchanged tissue,—that they consist entirely of coagulated albumen. This is a very remarkable fact, which as yet stands alone; for wherever in the parenchyme of plants we found protein, it was either a constituent of the incrusted cell-wall, or dissolved in the juices. These orange, granular, stellated bodies, after having been put in ammonia for some time, are dissolved and converted into a yellow fluid, which is diffused through the cell. The same result takes place through the action of nitric acid, followed by that of potash; showing that xantho-proteate of potash has been produced here. The cause of this protein being so exactly defined, is its being contained in internal utricles. This goes to prove that when the cells are young, the internal utricles are in close connection with the cell-walls.

† The cellular membranes which consist of pure cellulose become likewise swollen by nitric acid, and also by hydrochloric and other acids. This is no proof, therefore, of the presence of pectates in the wall, though in this case the swelling is greater than with pure cellulose. Turnips, which no longer produced any pectic acid, after being boiled with carbonate of soda, became much swollen by the influence of nitric and hydrochloric acids. See the articles under Pectic Acid and Xyloidin in Scheik. Onderz., Deel III. See also note, p. 389.

men in the contents of the cells, which have simply penetrated the wall, leaving, however, only traces in it. (Harting and Mulder.)

K. Spiral Vessels.

The cells of plants are distinguished by a general property to which too much attention cannot be paid, viz.: that the walls of the membrane being once duly formed, the substances are deposited on them in a spiral direction. We are unacquainted with the cause of this phenomenon, but the fact is certain. It has afforded a key to the discovery of a large number of the most beautiful particulars relating to the development of the organs and tissues in plants, and it therefore deserves special attention.

In young cells all that is to be seen is the internal utricle and a thin membrane of cellulose, by which it is enveloped. In a great variety of other cells, however, we discover a spiral body, convoluted on the internal wall of the cell, as a thin layer of a solid substance. If we imagine several cells united by a common axis, this spire may be traced from cell to cell. If that spiral deposit be accumulated in larger quantity, the cell is at the same time enlarged, and its membrane expanded. By this expansion the latter gradually begins to disappear at the point where the cells meet, and a small aperture is formed at the place of contact of the cells, which are united by one and the same axis. In this way there is produced a continuous canal, consisting of a great number of vesicles, which are in mutual communication by small apertures. The solid parts of the contents of the cell are invariably deposited at the spire, whilst at the same time the primary membrane continues to be expanded at the point of junction of the cells. The aperture at this point goes on increasing in size till it has reached its maximum; that is, till a continuous cylindrical canal has been formed, consisting of several cells, united into one whole, covered over internally by a single little spiral thread.

In this manner the canals are produced, which are called spiral vessels, and which occur very frequently in plants. They are not formed from the substance of the primary cellular membrane alone, but from this united with another substance deposited upon it.

The spiral thread itself is not hollow, as is thought by some. It is solid internally, having either a circular, an elliptic, or a quadrangular transverse section. The thread is pure white. Its convolutions often touch each other so as to produce an uninterrupted tube, which, if the vessels are neither too young nor too old, admits of being drawn out into the form of a corkscrew. In most cases the direction of the spiral is left-handed.*

These convolutions, however, do not always touch each other; sometimes the distance between them is considerable In some cases a few are united into one whole, which, when the spire is unrolled, adhere to each other much more strongly than those on each side of them do with their neighbours of the next set, thus forming, as it were, a band or cord of four, six, or more threads, between which a firmer adhesion exists. Sometimes several layers of spiral threads are seen rolled up close together, so that the tube consists of a number of threads, lying beside each other, and not unfrequently amounting to twenty in number.

The composition of the threads of the spiral vessels is not essentially different from that of the substance which forms the walls of the vessels, as long, at least, as the spire is young; but when it increases in age, an essential difference between them becomes apparent. In Agave Americana, fig. 50, the spiral threads of full-grown leaves became of a fine blue, like the walls of the spire, as soon as they were acted upon by iodine and sulphuric acid (4 parts of acid to 1 of water). The volume of the thread was at the same time considerably enlarged. In an old part of an entirely full grown leaf, only one

* It requires further investigation to prove whether the substance of the spire consists of two layers, a central and a cortical substance, and whether these are separated by potash into two, the one of which is starch, whilst the other is coloured yellow by iodine (Endlicher and Unger, Bot. S. 36). We have not found this observation confirmed.

single spire became immediately blue, while the others assumed the green colour of the bile (fig. 51). This proves that there are, at least, two different substances entering into their composition;—one of which becomes blue by iodine, whilst the other retains its yellowish brown colour. These older spires became also much less swollen than the young ones. Although the old leaves exhibit a stronger tinge of blue when strong sulphuric acid is applied, yet they always retain a greenish tint. The same is the case with the spires of Musa Paradisiaca, where they consist of a cord of five threads, traversed by dentated lines. By the action of iodine and sulphuric acid these threads turn greenish blue, are separated from each other, and present a dark blue space between them, owing to the transparent cell-wall.

By the application of strong nitric acid, the young threads of Agave Americana become swollen, and exhibit points, protruding alternately, without undergoing any further change. When an excess of ammonia is added, they become yellowish, which indicates the presence of a trace of protein. No difference in substance can be detected by applying a magnifying power either of 605 or of 788 linear. (Fig. 49.) In strong sulphuric acid they are immediately dissolved, and the colour becomes brownish. (Fig. 52.) They do not, therefore, consist of pure cellulose. Dilute sulphuric acid (4 parts to 1 of water) does not produce any change in the spires. (Fig. 46.) If strong sulphuric acid is then added, the thread is divided into small pieces, which are gradually dissolved. At the same time they become yellow, and when the thread is dissolved, yellow granules remain, which are much larger in size than the diameter of the thread, become smaller when acted on by ammonia, and are again much extended by potash. (Fig. 47.*)

* Aqua regia does not alter the old threads of Agave; it only makes them swell a little. Chromic acid has the same effect.

The threads are not changed by strong acetic acid. When, after this acid has acted for some time, ferrocyanide of potassium is added, no precipitate of protein is seen. After having been placed for two hours in a solution of bichloride of mercury, they have the same appearance as when they are seen in water.

It is worthy of remark, that in the same plant, even in the same leaf, the thread varies so much in thickness. Both the thicker and the thinner ones however, undergo the same changes when acted on by the above reagents.

When acted on by a strong solution of potash they become expanded, and their surface rough, but even after 24 hours they are not dissolved in it; they are not further changed by the addition of a fresh quantity of potash. (Fig. 48.)* In fig. 45 the threads are represented as they appear in water.

In Phytolacca decandra the spiral threads become yellow when treated with strong nitric acid, especially after the action of ammonia. These, therefore, contain also traces of protein. (Harting and Mulder.)

Mitscherlich has analysed the entire spiral vessels of the Pisang (p. 208), that is, the membrane of cellulose, and the thread which contains cellulose, a trace of protein and a third substance besides. Payen obtained from the threads alone of Musa sapientum (Mém. p. 219),—

C	48.43
H	6.91
O	44.66

—which is the same proportion of carbon as was found by myself. The hydrogen, however, is evidently incorrect here, and as Mitscherlich has not given the proportion he found, we are still unacquainted with their composition.

It was a matter of importance to find out the composition of the spiral threads, as the reagents mentioned indicate that, besides cellulose, they contain the substance which constitutes the intermediate layer of the woody cells or the true woody matter; this may be inferred, at least, from what has been observed in old spiral threads. In woody cells three different substances occur, viz., that of the external layer, that of the middle one, and cellulose, which we are, as yet, unable to separate from one another; and, therefore, the analysis of an elementary tissue containing only two of these substances will be of much service in bringing us nearer to the knowledge of the pure intermediate woody matter. The composition of cellulose is known; the protein can be extracted from the spiral threads by strong acetic acid; and if, then, from the entire formula—given by the analysis of the spiral threads purified in this way, and treated further with a weak acid, alcohol, ether, and

* They would undoubtedly be dissolved in a large quantity of potash.

water,—that of cellulose is subtracted, the remainder will represent the composition of the pure and real substance of which the intermediate layer of the woody cells consists.

I have examined in this way the spiral threads from Agave Americana,—purified by means of strong acetic acid, water, alcohol, and ether. They left above 2 per cent. of ash, which, therefore, could not be removed by acetic acid. Dried at 266° F. they gave—

	Found.	Atoms.	Calculated.
C	47.65	64	47.94
H	6.04	49	5.99
O	46.31	47	46.07*

The result of this analysis represents a mixture of two substances, of which one—cellulose—is known. Subtracting the formula of the latter from that which is above given, we have—

	C	H	O
	64	49	47
Cellulose,	24	21	21
Woody matter,	40	28	26

	Atoms.	Calculated.
C	40	50.89
H	28	5.82
O	26	43.29

We shall speak of this more in detail under the section on wood, and will only remark here, that it differs from ulmin, into which it is so readily converted, only by the elements of water.

	C	H	O
Woody matter,	40	28	26
Ulmin,	40	14	12
		14	14

This woody matter, which corresponds to the intermediate layer of the woody cells, we shall distinguish by the name of

* Scheikund. Onderz., Deel III.

intermediate woody matter, whilst to that of the external layer, we shall give that of *exterior woody matter*.

In Mamillaria pusilla,—which has broad, large, and flat spires,—the spiral threads, taken from the spot where the stem passes into the rhizoma, undergo no change by the action of potash except that they become more transparent. The cell-wall, under the influence of this reagent, is rapidly made transparent. By the action of strong nitric acid, the rings which are visible on the transverse section, become yellowish; if an excess of ammonia is then added, a very distinct yellow colour is produced, owing to the formation of xantho-proteate of ammonia,—this is much stronger than in Agave or Opuntia. (Fig. 53.) The threads remain perfectly homogeneous, and become somewhat swollen. The longitudinal section of the cell-wall, when treated with nitric acid and ammonia, does not exhibit any change of colour. (Fig. 54.) By tincture of iodine both the spires and the cell-wall are coloured brown; by the addition of sulphuric acid, diluted with a fourth part of water, they do not turn blue, but when the mono-hydrate of sulphuric acid is used, the cell-walls are dissolved into a fine blue liquid, whilst the spires continue brown. (Fig. 55.) After some time the latter assume the green colour of bile. (Fig. 56 and 57.) They appear perfectly homogeneous, and after half an hour they become brownish red (fig. 58), by the action of the strong acid, and after twenty-four hours this colour is still unchanged. Neither the spires nor the walls are affected by diluted sulphuric acid; but if strong sulphuric acid is subsequently added, the walls are first dissolved, and then gradually the spires, which at first are colourless, but finally become brownish,—without leaving any granular residue, as is the case in Agave. Along with the spires—much later, therefore, than the walls of the spiral cells—the medullary cells are dissolved, which shows that the substance of which they consist is far more consolidated than the walls of the spiral cells. Some pieces of the spires are seen undissolved even after the action of 24 hours.*

* Neither the spires nor the cellular membranes undergo any change after having been treated with chlorine water for 24 hours, at the common tempera-

This indicates a difference between the spires of the spiral in these species and those in other plants. Only a very small part of them seems to be cellulose, but they contain a large quantity of the intermediate ligneous matter.

An analysis of the spiral vessels of Mamillaria promised to be of importance, because we could thus find by approximation the composition of the spires. The ligneous body of Mamillaria pusilla, which consists of about 80 per cent. of spires, 10 per cent. of medullary rays, and 10 per cent. of spiral tubes, and takes the place of the wood in the dicotyledonous plants, as the dotted cells *(tüpfel-cells)* do in the coniferous,—after being treated with alcohol, water, and ether, approached near to that of pure woody matter. The presence of the very thin membrane of the spiral cells, and the medullary rays, is the cause that this identity of composition is less exact (see p. 423), than that of the isolated spires would be. The results were:—

	Dried at 266° F.	275° F.
C	50.49	50.25
H	6.10	6.10
O N	43.41	43.65*

As the ash in this substance amounts to 6 or 7 per cent., the result of the analysis cannot be very exact; besides, it contains protein, as wood does. It may suffice to observe, that the spires of Mamillaria appear to be intermediate woody matter

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ture. When digested with strong hydrochloric acid for an equal period in the air, the cellular membranes do not change their colour, but the spires become of a light violet. (Fig. 59.) This shows the presence of a trace of protein. (This reagent for protein surpasses in delicacy nitric acid with ammonia, and affords an excellent means for detecting protein in vegetable tissues.) When digested with strong nitric acid for 24 hours, at 140° F., both the cellular membranes and the spires appear very much inflated, and have become very transparent. Digestion with a strong potash-ley at the same temperature produces the same effect, and renders the colour yellowish brown. After the whole of the alkali has been washed out with water, the application of iodine and sulphuric acid still produces the same blue colour in the cellular membranes, but the spires become brown. (Harting and Mulder.)

* Scheikund. Onderz., Deel III.

in which almost no cellulose can be detected. In comparing the spires of Agave with those of Mamillaria, we perceive a difference in the quantity, but not in the nature of the substances of which the threads consist. Those of the former, even when old, contain much more cellulose than those of the latter; which in their turn contain a much greater quantity of the intermediate woody matter, and along with this more protein also. We have found it to be uniformly the case that, when the intermediate woody matter in any elementary tissue is on the increase, the protein increases in the same ratio. The latter accompanies the former. While the protein is itself in the act of decomposition, it must produce this intermediate woody matter from the contents of the cell, and whilst effecting this change, a part of it, which is left undecomposed, is enclosed within the substance of the newly formed solid body. This is the cause why the protein is found in old and incrusted, but not in young layers.

The broad spires of Mamillaria, though we have not examined them whilst young, must be formed in the same manner as those of Agave americana. The first traces must be spiral incrustations of woody matter deposited on the cell-wall, but mixed with a great deal of cellulose. The proportion of the former increases gradually, whilst that of the latter decreases, and it finally disappears altogether, either in reality or apparently.

The same substance, therefore, gives rise to the formation of spires, and of layers of woody matter in the ligneous cells, the only difference being in the spot where deposition takes place. In the spiral vessels this is effected on the internal wall, and in a spiral direction; but in the ligneous cells it penetrates in layers *through* the cell-wall outwards.

The wall of the spiral vessels is always pure cellulose.

L. Annular, Reticulated, Striated, Punctated Vessels.

It does not always happen that the spiral layer of matter, which is deposited in some cellular systems upon the membrane of cellulose in the form of a distinct spire, produces

either such spires as we have been describing, or spiral vessels duly developed. If between the cells that adjoin each other no pore of communication is produced, the cells remain isolated from each other, and either retain the spire, or new products of the latter are deposited in them. If the adhering cells acquire a common aperture, while the spire remains but imperfectly developed, the vessel produced has a different shape from the spiral vessels.

These are the means through which nature forms several kinds of vessels in plants.

When the isolated convolutions of a spire are placed close to one another, they resemble a ring in appearance. If two, three, or more convolutions of a spire, deposited on the inside of a cell, adhere to each other, and the cellular membrane then becomes expanded, this set of convolutions is apt to be torn off from the remainder of the spire, and a ring is in this way produced. If such a partial adhesion of a small number of convolutions takes place over the whole length of the spire, then the consequence is that, by the expansion of the cellular membrane, and the subsequent separation of these several parts, a set of rings is formed, which are united together by the cellular membrane; in other words, an annular cell is produced. Finally, if we imagine such a change to take place in a series of cells, united together by one axis, and that the several walls of division between them disappear, *an annular vessel* is produced, being a tube originally consisting of cells which were incrusted in a spiral direction,—a tube which may extend to a considerable length within the plant. These rings, like the spires, contain incrusting matter, and are united by the membrane of the cell in which this incrustation has originally taken place.

There can be no doubt as to the origin of these annular vessels; since between the rings small fragments of the spires may often be seen, which have escaped the general transformation.

Reticulated vessels are produced in a similar manner from substances deposited in a spiral direction upon the cell-walls. In their formation, however, this difference exists,

that the spiral convolutions are detached—not regularly, as is the case with the rings,—but irregularly; the consequence of which is, that in various spots of these vessels there may be seen small, isolated portions of the incrusting matter, which was originally deposited in a spiral direction.

If these portions have a regular appearance, the vessels receive the name of *striated*; they are regular parts of convolutions which do not extend to the formation of a complete ring.

Finally, if these portions of the spire, which are externally visible, are very minute but in great number,—in other words, if the convolutions are divided into innumerable small portions, then we perceive in the midst of them, on the spots where the portions of the spire have separated from each other, a number of *points*, and hence the vessels thus produced have received the name of *punctated* vessels. Like the others, they consist of the cellular membranes, covered internally with portions of the spire which had been deposited within the cells in the shape of incrusting matter.

It is quite certain that all the vessels in plants are, without exception, produced from cells, and that their several varieties originate in the ways just mentioned. In proof of the first statement, even in vessels of an advanced state, we find irregularities of such a kind as can only be accounted for by reference to their cellular origin,—such as their being contracted at distances which are proportionate to the size of the cells, and which represent remainders of the original transverse walls of the cells.

Although, in our opinion, one and the same primary cause, —viz., the spiral deposition of a thin layer of matter (intermediate woody matter) on the cell-wall,—is the source to which the cell-walls owe their incrustation; spiral vessels, their development; and annular, reticulated, striated, and punctated vessels, their existence;—it must not, however, be imagined, that these forms are convertible into each other, either arbitrarily, or by a small variation of conditions, so that a punctated or a striated vessel can be considered as an imperfect spiral vessel. Such is by no means the case. There is a perfect stability in the development of the several forms

we have been describing from the same fundamental form, from the same simple principle employed by Nature. It is most evident that in the organic kingdom, by means of the deposition of substances in a spiral direction, the organs we refer to are formed in accordance with fixed principles, and that each of these organs must be regarded as perfect of its kind. It is through this property of plants, of either secreting substances, or developing elementary parts invariably in a spiral direction, that even the division of branches and leaves is subject to the most striking regularity; and the apparent confusion which attends it, has by Schimper and Braun been reduced to the most beautiful order by referring it to this predisposition to the formation of spires.

Nothing certain was known concerning the substances of which all these kinds of vessels are formed. It was certain that cellulose is present in the walls of the vessels, but to this part of their composition our knowledge was limited. We give some of our observations made on the subject.

1° *Annular cells* are identical as to the material of their walls with parenchymatical cells; that is, they consist of pure cellulose. But the rings themselves are of a peculiar nature, and differ more or less from the spires of the spiral vessels, being similar to those of the spiral cells.

A strong potash solution causes the rings of Opuntia microdasis to swell, (fig. 60, 61, 62, 63, 64.) They remain perfectly homogeneous, uncoloured, and are not dissolved.

Strong nitric acid makes them swell; they remain uncoloured: but on the addition of an excess of ammonia, a trace of protein is detected, (fig. 63.)

Strong sulphuric acid has the effect of immediately dissolving the cell-wall, while the rings swell and become transparent. The latter remain perfectly homogeneous, while numerous minute apertures appear in them, and they acquire a crenulated internal rim. A yellow colour is produced, (fig. 61.) They are not dissolved by an excess of strong sulphuric acid, even after the action has been continued for an hour. The spires present in the objects examined are affected in exactly the same manner.

The rings continue to remain undissolved after strong sul-

phuric acid has acted upon them for twenty-four hours. By the addition of tincture of iodine they do not turn blue, but brown, (fig. 62.) Several superimposed layers rapidly appear, —in some three, in others four in number,—separated from each other by dark lines. There are, however, some amongst them, which do not exhibit such layers; and a few of these are surrounded externally by a thin, very dark coloured band, and have in their interior a clear colourless part, which is the aperture, (fig. 62.)

When a dry object is moistened with strong sulphuric acid, the rings become much swollen, and are dissolved a little before the spires which are present. At first the colour is greenish, (fig. 64,) and becomes brownish afterwards. Not a trace is left undissolved so far as can be detected.

On the application of tincture of iodine and sulphuric acid (4 parts acid to 1 of water), the rings turn yellow. If strong sulphuric acid is then added, they become of a dark yellow, and subsequently of a bile-green, but not blue; whilst the merenchymatic cells, and the walls of the annular and spiral cells, become immediately of a beautiful blue. The spires of the latter acquire the same green colour as the rings. The transition of spires into rings, which we observed in several instances, receives additional support from these reactions, as they show that both spires and rings are composed of the same substances. (Fig. 60.*)

The rings of the annular vessels (striated cells) of Vitis vinifera, (fig. 44, *c*) exhibit the same phenomena as those here mentioned. (Harting and Mulder.)

The walls of the annular cells, therefore, consist of cellulose, and, as it appears, of nothing else; but the rings contain only a trace of it. As, however, they consisted formerly entirely of cellulose, (see *Spiral Vessels*), and now exhibit the characters of the intermediate wall of the woody cells, the rings during their development must have undergone a considerable change. The reactions exhibited by the substance composing them seem to indicate that it is similar to the in-

* Chromic acid produces no other change in the rings than to make them swell. Aqua regia does the same. The spires are similarly affected.

crusting layers of Hoya, and therefore consists of a little cellulose with much of the intermediate ligneous matter. The wall that constitutes the exterior covering of the transverse section of the rings of the annular cells, contains more of this peculiar ligneous matter, and less cellulose, than the other part of the rings.

Hence it follows, that ligneous matter is formed from the contents of the cell, penetrates *into* the spire and incrusts it, partly by intus-susception, partly by super-position, as takes place in the woody cells of Hoya.

2° The *reticulated vessels*, as observed in Tradescantia virginica, are exactly analogous to the annular and spiral vessels. We observed, in several transverse sections, that the same vessel contained rings and spires. The cell-wall becomes dark blue by the action of iodine and sulphuric acid, but the rings themselves greenish-yellow. (Harting and Mulder.)

3° The *scaliform vessels*, so far as we have examined them, have shown a peculiar relation to reagents. We first examined those of Aspidium filix mas, where a large number of them is found in a bundle of vessels, of which the transverse section presents a dark rim. The thick wall by which the bundle is surrounded, is not dissolved in sulphuric acid (4 parts acid to 1 of water)—thus proving to be similar, in this respect, to the cuticle of plants and the exterior layer of the woody cells. On being treated with iodine and sulphuric acid, it assumes a brown colour. The scaliform vessels themselves, when acted upon by iodine and sulphuric acid, become externally brownish, and do not exhibit any distinct structure or succession of layers. A vessel of this kind, when cut longitudinally, presents the appearance of isolated, yellowish-green fragments, lying in a transverse direction, so that the transparent spots of a scaliform vessel are really slits. There cannot be present in these vessels any thin cellular membrane, surrounding the annular portions, as from the very first moment of action no blue colour could be seen in the spaces between the rings.

The same substance, therefore, that forms the rings of the annular vessels, (the intermediate ligneous matter,) constitutes the annular parts of the scaliform vessels; whilst the

exterior layer by which they are surrounded, and which becomes brown under the action of iodine and sulphuric acid, seems to be of another character, and in this instance analogous to the exterior layer of the ligneous cells. (See *Ligneous Cells.*)

After forty-eight hours every thing appears the same. If strong sulphuric acid is then added, some vessels turn dark brown, others yellow, and others green. The broader ones become brown, and those which are thinner, green. This cannot be attributed to a difference in age, for all the vessels that constitute the bundle, are alike developed from the bud at once.

A difference in dimension, however, can only be caused by difference in development; and as the thinner vessels become green, they still contain some cellulose, which does not seem to exist to any sensible amount in the older ones.

This fact deserves our special attention, because it indicates an actual change of cellulose into another substance, or at least a replacement of cellulose by something else. Whilst some tissues, from their very first to their highest development, always contain cellulose, it constantly diminishes in others, and finally disappears altogether after having made room for another substance, which in the present case is the intermediate woody matter.

In this respect, therefore, the tissues of plants are analogous to those of animals. The cartilaginous tissue in the bones is converted into gelatinous tissue; in the skin and serous membranes, the gelatinous tissue always retains its original character unchanged.

In Vitis vinifera the scaliform vessels are accompanied by *porous* vessels. Whilst the medullary cells, under the action of iodine and sulphuric acid, become of a bright blue, the annular and spiral vessels become brown internally. The porous vessels present, in their longitudinal section, here and there colourless apertures (fig. 44), which have a blue colour if the vessel itself has not been cut. In the thick-walled parenchymatical cells of Cicas revoluta, fig. 28, the exterior layer of the wall, (that which externally surrounds

the ligneous cells, and which we distinguish by the name of outer ligneous matter) is brownish,—and the internal tegument (cellulose) is blue. Hence, in a longitudinal section, the true apertures must present the real appearance of the blue internal tegument. But the stem of Vitis vinifera contains also other porous vessels of which the pores are green. These are the spots where real hollows or pits (*hofstippels*) are situated, where the brown membrane is very thin, and hence the blue shining through it appears green.

There are, therefore, two distinct walls in the porous vessels, which, as the one becomes blue and the other brown, must consist of two different substances. Besides, there are two kinds of pores which are produced either by corresponding apertures in both the walls, or by canals in the external walls which open internally.

The transverse section of the porous vessels exhibits some similarity with that of the ligneous cells. They are not only thick-walled, like the latter, but they sometimes contain internally a very thin, brown, granular membrane, (internal utricle?) which is contracted by iodine and sulphuric acid. They differ, however, from the ligneous cells in respect of the intermediate wall—situated between the external wall which is turned brown, and the thin internal utricle, just mentioned,—which in them is pure cellulose ; whilst in the ligneous cells it consists of several layers, of which only the innermost is pure cellulose. The porous vessels may, therefore, be called ligneous cells, free from the intermediate woody matter.

In Vitis vinifera we have most distinctly seen the transition of scaliform into porous vessels ; whence it appears, that both have the same origin, and are produced in the same manner. We observed in the longitudinal section of a single long vessel, that one part of it was scaliform, and another part porous.

We also found the external wall which became brown, and an internal one which turned blue, by the action of iodine and sulphuric acid, as mentioned above,—in the porous vessels of Euphorbia caput-medusæ, and in the punctated vessels of Asclepias syriaca.

M. Incrusted Cell-walls.

We have now reached the formation of hollows in the cell-walls (*tüpfel formation*), which has given rise to so much discussion, and which is partly connected with the question, whether the incrustation of the cell-wall takes place *on the inside*, or *on the outside* of the walls of the primary cellular membrane.*

I shall not venture to pronounce any decisive judgment in a matter that has been so thoroughly investigated by the most eminent labourers in this department of science; but nobody will think it unbecoming, that I simply communicate the observations which I have made on the subject in concert with Professor Harting, and that I draw from them such conclusions as they have naturally induced me to do.

Setting aside the question whether the primordial utricle be really primordial, it has become evident, from the objects examined by us, that the same kind of incrustation does not take place every where, and that the subject cannot be viewed from one point alone. If the cellular membrane—which turns blue by the action of iodine and sulphuric acid, which exists in the very youngest tissues, and which is un-incrusted in the young ligneous cells—be a permanent one, then in the formation of wood it is incrusted *externally*; for such a membrane consisting of cellulose is always found within the incrusted walls. The *tüpfel*-formation takes place in all those cases by a deposition of layers *around* the primary cell, and upon these a third very distinct layer is deposited, to which we shall give the name of the cuticle of the ligneous cell, and which completely incloses the incrusting layer. (Fig. 31, Clematis vitalba, fig. 36, ditto.)

But another and different incrustation takes place besides this external one, viz., on the *inside* of the cell-wall consisting of cellulose. This is most distinctly visible in the thick-walled medullary cells of Hoya carnosa, (fig. 41 and 42.)

* See Mohl über den Bau der getüpfelten Gefässe. Linnæa, Bd. 6, H. 1, S. 1.

Lastly, a third kind of incrustation takes place *in* the cell-wall itself, which does not produce any visible deposition in layers,—as is seen in the albumen of the seeds of Phytelephas, (fig. 84 and 85,) and of Iris cruciata, (fig. 81 and 82.)

It appears, therefore, that we ought to assume three distinct kinds of incrustation of the cell-wall.

The *incrusted and tüpfel or pit-shaped cell-walls*, therefore, deserve a detailed treatment. We shall commence with giving some account of the appearances produced in those of various plants by different reagents.

Those of a young branch of Hoya carnosa of the second internode, counted from the top, on being treated with strong nitric acid, exhibit nothing particular. With iodine and sulphuric acid (4 parts to 1 of water), they remain brown, and swell a little. The woody cells resist the action of ordinary concentrated sulphuric acid; they become yellow, however, and everything else except the cuticle and the hairs is dissolved.

The ligneous cells from the fourth internode of Hoya become intensely yellow under the action of nitric acid, (fig. 1, A *f*) like the incrusted medullary cells (see *medulla*). Iodine and sulphuric acid (4 parts to 1 of water) colour them brown. (Fig. 1, B *f*.) Those of the seventh internode undergo the same reaction. The very young woody cells, however, (the cells of cambium of the second layer) become of a beautiful blue (fig. 1, B *e*); a fact confirmatory of an observation we have frequently made, that the primary cellulose is afterwards either changed into, or replaced by another substance. These cells are not incrusted, and the contents are brown.

The woody cells of the fourth internode, treated with sulphuric acid, become greenish yellow, swell up, and exhibit concentric layers; the swelling is so great as to make the lumen almost entirely disappear. At last the whole is dissolved, and the woody cells leave a membrane behind, which constitutes the external wall. Some of them have the appearance of a little net of brown hexagonal meshes.

The same reaction is observed in the seventh internode,

but here it takes place more slowly. After forty-eight hours the contents of the woody cells have become brown and shapeless.

This reaction indicates the presence of a peculiar substance in ligneous cells of the fourth internode of Hoya, either produced from or substituted for cellulose. But, whilst the seventh internode seems to contain real woody matter, which is converted by sulphuric acid into ulmic acid, and while the cells are enveloped in a thin membrane, which is insoluble in sulphuric acid (exterior matter of the ligneous cells), there is still much wanting, which is peculiar to the ligneous or woody cells of other plants. (See *Ligneous Cells.*)

The cellulose disappears very slowly, as is shown by the production of a bright green colour in the young woody cells of Hoya, under the action of iodine and sulphuric acid, which we observed in the fourth internode—a phenomenon which was also exhibited by the incrusted medullary cells of the same preparation. It is remarkable that there is so much similarity between the woody and incrusted medullary cells as regards the incrusting matter itself. It would appear, that before the incrustation it is one simple substance, and does not consist of a mixture of different substances, as it does in the other woody cells.

In a very old branch of Hoya, which distinctly exhibited the concentric layers, and where the incrustation was so thick that the canal or lumen of the cells could scarcely be longer distinguished, the incrusted wall—as is also that of the incrusted medullary cells—is coloured by strong sulphuric acid, first bright green, and then brown. The medullary cells, which are dissolved by this treatment, undergo that transformation first on the outside.

The seeds of Alstrœmeria aurea, (fig. 76, 77, 78, 79, 80,) which present beautiful hollows (tüpfel) formed out of the albumen, consist of a tissue which is called horny albumen, and is semi-transparent. By the application of strong nitric acid, the thick cell-walls become swollen, and the *tüpfel*, or pits, are closed. They do not assume even the slightest yellow colour, and hardly so on the addition of ammonia. Only traces

of protein, therefore, are present. When treated with iodine and sulphuric acid, (4 parts to 1 of water), they do not turn blue but pale yellow. (Fig. 80.) After some time those near the epidermis become blue, the others very slightly reddish violet. They do not swell, but are dissolved. It would appear, therefore, that they consist of a peculiar substance. They are also not turned blue by the application of strong sulphuric acid after that of iodine, with the exception, as before, of those which lie near the surface. As the latter have the same form as the rest, they appear to be gradually converted into the peculiar substance mentioned. In the cells, pure globules of oil can be seen without any other substance existing between them.

By potash the incrusted walls become swollen, but even after some time the pits are still distinctly visible.

The very young seeds have this important peculiarity that they do not become blue by the action of iodine and sulphuric acid, but are rapidly dissolved. No globules of oil are present, but though devoid of starch, they appear to contain a granular substance. The walls of the young cells are very thick, and studded with a considerable number of pits. The younger the cell-wall is, the less it is coloured by iodine alone, which is the more remarkable as the young cell-wall is very soft, and the old, on the contrary, very hard.

No layers whatever can be perceived in the cell-wall.

In the seeds of Iris cruciata, (fig. 81, 82, 83), the cell-walls are found incrusted in a manner similar to those of the seeds of Alstrœmeria. The thickness of the walls is 0.0054 millimetre. They are, however, affected by iodine and sulphuric acid differently from those of Alstrœmeria. By iodine alone they are coloured brown. Not a trace of concentric layers is to be seen. By strong sulphuric acid the incrusted cell-wall is then suddenly coloured blue and dissolved. (Fig. 83.) But by the action of iodine and sulphuric acid, (4 parts to 1 of water), it becomes brown, (fig. 82), and presents hexagonal figures, of which, previous to the application of the acid, not a trace was to be seen. The brown colour is not the consequence of a decomposing influence of the acid, for after forty-

eight hours the addition of ammonia restores everything to its original state, as if no reagents had been applied.

The seeds of Phytelephas macrocarpa, a transverse section of which is represented in figs. 84 and 85, become light blue after the action of iodine and sulphuric acid, (fig. 85), and are lined with white rims. They also now present the appearance of hexagonal sections, whilst not a trace of any regularity could be seen before the application of the reagents. The blue colour soon disappears, and is changed into white.

The seeds of Phytelephas having been analysed before, and having given the composition of cellulose (p. 200), it became a matter of importance to determine that of the seeds of Alstrœmeria and Iris. Both were first separated from the epidermis, those of the Iris having also the embryo removed, then pulverised, digested subsequently with ether, water, and alcohol, and analysed. The proportion of ash they contained was invariable; but in both the carbon did not burn away till after long protracted ignition.

	Seeds of Iris dried at	Seeds of Alstrœmeria dried at		Atoms.	Calculated.
	266°	266°	292°		
C	45.99	45.86	45.65	24	46.14
H	6.16	6.25	6.23	19	5.98
O	47.85	47.89	48.12	19	47.88*

The composition of these seeds thus appears to be very simple. They are isomeric with mucilage (Scheikund. Onderz. Deel III.), and differ from cellulose, of which the seeds of Phytelephas partly consist, by containing 2 equivalents of water less. ($C^{24} H^{21} O^{21} - 2 H O = C^{24} H^{19} O^{19}$.) The quantity of protein is so very minute, that it cannot influence the result of the analysis. The proportion of cellulose is also very small.

This tissue, therefore, has been produced from cellulose by the loss of the elements of water. In that of Iris, however, a trace of cellulose has still been left. (Fig. 83.)

* Scheikund. Onderz., Deel III.

The seeds of Phytelephas, which exhibited a much less distinct blue reaction than pure cellulose does, contain still another substance, different from cellulose in properties, but not in composition. (See Von Baumhauer in Scheikund. Onderz., Deel II. and Deel III.)

The substance by which the cell-wall in Hoya carnosa is incrusted, seems to be an intimate mixture of cellulose with what we have called *intermediate ligneous matter*. The latter is a product of the contents of the cell, and in Hoya carnosa is intimately interwoven with the layer of cellulose, but in the woody cells, properly so called, is transuded through this layer. In both of them, however, the contents of the cells, by transmission through the layer of cellulose, first give rise to the production of a peculiar little wall, which is not dissolved in strong sulphuric acid; this is the membrane of the woody cells. (Harting and Mulder.) (See further, ***Ligneous Cells.***)

N. The Sap Vessels.

Plants contain a peculiar series of vessels which are the conveyers of fluids, and which, in vascular plants, often attain to a considerable length. They are called ***milk or sap vessels.*** It is known that their structure differs from that of all the other vessels and cells in plants. When young, they consist of thin walls, which grow thicker with the age of the plant.

These vessels are most frequently cylindrical, have mutual communication by lateral anastomoses, run parallel to each other in the stems, and in the leaves form a kind of ramifications which open into, or anastomose with each other, though by no means to be compared in this respect with the blood-vessels in animals. They exhibit no power of contraction, and we are, as yet, unacquainted both with their commencement and with their termination.*

It is considered as an observed fact that these vessels, when advancing in age, acquire transverse partition walls

* See Meyen, Secretions-organe der Pflanzen, S. 66.

at small intervals, which deprive them of their function of carrying fluids, and give them the appearance of elongated cells. I cannot decide this point.

It is probable that they are formed from adjoining cells in which the intervening walls have been absorbed at the point of contact.

The sap-vessels undoubtedly perform an important function, though its exact nature is still the subject of much discussion. In general the cells of plants can give passage through their walls only to a clear transparent liquid; for these walls are the finest filters that are known. (See p. 211.) The liquid that passes from one cell into another,—that is, through two of these filters—cannot hold any particles in suspension. Much less can this be the case with the liquid that has ascended endosmotically through an innumerable multitude of cell-walls, excepting in the case of those cells in which pores do really exist (see p. 403), which, perhaps, occur much more frequently than is yet supposed, though such pores must be very minute, and by no means capable of giving passage to coarser particles. Hence it follows, that into no cell can any solid body be introduced, nor can any be removed from it, except in a state of solution, with the single exception of those cells, whose walls do actually contain pores (p. 403).

With the sap-vessels the case is entirely different. Although their internal bore is much smaller than that of the spiral vessels, yet it is an open canal through which turbid fluids, such as hold small solid particles in suspension, may ascend. In most cases the contents of these sap-vessels are not clear, whence they are sometimes called *milk-vessels*, and the small bodies that are floating in the liquid, *globules of the lactic juice*. It is self-evident, however, that this fluid is of an entirely different nature from the animal fluid to which the same name is given. (See *Vegetable Juices*.)

The milk vessels (*Vasa laticis*,) of which we shall treat here in combination with the *lactiferous cells* of the bark, consist principally of pure cellulose.

As regards the latter, we observed it become blue under the

action of iodine and sulphuric acid, when taken from a second internode from the top in Hoya carnosa. (Fig. 1, B *d*.)

Those of Asclepias syriaca, where lactiferous fibrous cells of the bark occur, are found to turn blue, and to exhibit concentric layers under the action of iodine and sulphuric acid, (fig 15.) Those found in the pith of this plant, which convey much lactic juice, exhibit the same phenomena with these reagents.

The former, we have been able to examine thoroughly in Euphorbia caput-medusæ, (fig. 66,) where they form a ring round the woody bundles, and are also scattered through the parenchymatic layer of the epidermis. On a transverse section these *vasa laticis* present very thick walls, which can also be most distinctly seen on the longitudinal section. By the action of iodine and sulphuric acid these vessels become rapidly of a very dark blue,—much sooner than the neighbouring ligneous cells, which also assume a fine blue colour, (fig. 67.) On the transverse section of the lactiferous vessels coloured in this manner, a dark blue substance is to be seen, which lightens in tint from the centre towards the circumference, and around which we find a bluish white rim, a thin brown layer, and beyond that a white rim again (the last due to an empty space) which touches the parenchymatic cell, (fig. 68.) We see from these phenomena, which appear immediately after the action of the reagents, that this lactiferous vessel contains two different substances, of which the exterior becomes pale, the interior intense blue, and that these two radiate into each other. The transverse section, also, even before it is coloured, presents distinctly radiated lines indicative of the insensible intermixture of these different substances. The clear rim around the whole is simply due to empty space.

The truth of the latter statement is proved by moistening it with strong nitric acid. This causes the lactiferous vessels to swell very much, as may be seen on the transverse section, whilst both the aperture and the clear rim around the whole disappear. In this state also the radiating division of the substances composing the wall is rendered dis-

tinctly visible. By the subsequent addition of an excess of ammonia they are not coloured yellow, any more than by nitric acid alone, but remain colourless.

By strong potash they are affected in the same manner as by nitric acid; they become very much swollen, the passage and the exterior light rim disappear, but concentric layers are made visible.

We have further investigated the nature of these vessels on a longitudinal section. By the action of iodine alone the contents become dark brown and granular, the wall light yellow. By the subsequent addition of sulphuric acid (4 parts to 1 of water), the vessels immediately become of a very intense blue, and there appears around the outermost circumference a very thin granular membrane of a dark brown colour, having a thickness of from 0.0005 to 0.0007 of a millemeter (fig. 68). (Harting and Mulder.)

The lactiferous vessels, therefore, contain three different substances; the innermost layer is cellulose; around this lies another, which becomes much swollen when acted on by potash and by nitric acid (pectose?); and then an outermost, exceedingly thin layer of a substance, which, as far as can be deduced from the few properties yet observed, is analogous to the exterior layer of the ligneous cells.

O. The Chemical Character of the Elementary Constituents of the Stem in Dicotyledonous Plants.

As our observations have been principally directed to the elementary tissues of dicotyledonous plants, we shall examine somewhat more closely the elementary parts of these plants in the order in which they occur, and treat at the same time of those of the few monocotyledonous plants, which we examined, when their corresponding tissues are under consideration.

P. Medullary Cells.

The medullary cells differ considerably, not only from

other elementary tissues, but also from one another in the same plant. Along with them I shall treat of the cells of the medullary rays.

The medullary cells in Mamillaria pusilla undergo no change of colour by the action of nitric acid and ammonia, but when treated with iodine and sulphuric acid (4 parts to 1 of water), they instantly become blue. The cells of the medullary rays are not affected by a strong solution of potash. In the medullary cells of the elder tree, on the contrary, iodine with sulphuric acid (4 parts to 1 of water) produces no change of colour at all, even in those of the youngest internode; the substance, therefore, of which this pith consists seems to be of a peculiar nature. Hence, it would be of importance to submit it again to an accurate elementary analysis. A transverse slice of a petiole of the elder tree, again, was not discoloured in the pith by the action of iodine and sulphuric acid, (4 parts to 1 of water), though the blue colour showed itself as soon as the mono-hydrate of sulphuric acid was added. It would appear, therefore, that the pith of the elder tree, when very young, contains cellulose, which, however, is soon changed into another substance; and that in its very young state it requires a stronger sulphuric acid to produce the same reaction which is instantly exhibited under the influence of the weaker acid, by the stone fruits of Phytelephas. The walls of the medullary cells of the petiole, just mentioned, were exceedingly thin,—only from 0.0003 to 0.0010 millemeter in thickness,—and still free from incrustation. Those of the same internode, which did not become blue, had a thickness of 0.0004 to 0.0012 of a millemeter, that is, nearly the same as the former. This again removes every doubt that either transformation or substitution of the cellulose of the cell-wall takes place.

The medullary cells of Hoya carnosa (fig. 1), exhibit a perceptible diversity, according as they are taken from different internodes. In the very youngest alone no incrustation of the walls can be perceived. In the third internode, counted from the top, a few medullary cells with incrusted walls already appear amongst the others; and a greater number in the sixth internode, in which the pits or *tüpfel* may be very

distinctly seen. The thinnest wall, existing in the second internode, is 0.0009 of a millemeter in thickness, and the thickest 0.0016 millemeter. The unincrusted medullary cells in the second internode are not changed in colour by nitric acid, but present internal utricles, which instantly become of a fine blue, when iodine and sulphuric acid (4 parts to 1 of water) are applied. When a little concentrated sulphuric acid is put upon a dried transverse section, the medullary cells are seen rapidly to dissolve.

In a section of the fourth internode, the unincrusted medullary cells are not changed by nitric acid; but the incrusted cells become of an intense yellow, and exhibit concentric layers. Their colour is then the same as that of the ligneous cells of Hoya, when exposed to the action of the same reagents. After ammonia has been added, they both become dark yellow, and thus appear to contain an equal quantity of protein (fig. 1, A *i*). Under the action of iodine and sulphuric acid the unincrusted medullary cells of this fourth internode become instantly blue, whilst those that are incrusted do not give a trace of that colour, but exhibit the yellow colour of the iodine (fig. 1, B *i i*). This remarkable fact indicates that in these last the cellulose has been entirely replaced by or converted into other substances. Those of the seventh internode give the same reactions. Under a magnifying power of 280, the interior face of the brown wall of the incrusted medullary cells, which have been acted on by iodine and sulphuric acid, is seen to be covered with a thin green membrane, consisting of cellulose, but interwoven with traces of the substance which constitutes the brown-coloured incrusted wall. Here also, therefore, we find conclusive proofs of a transudation of the substances that incrust the wall from the inside to the outside, as all the medullary cells before their incrustation consist of cellulose, and after the incrustation the cellulose is found inside.

Strong sulphuric acid, which readily dissolved the thin-walled medullary cells, does not dissolve the incrusted cells, but merely makes them swell as it does the ligneous cells. In this respect also, therefore, there is a great analogy between

these two kinds of cells. The medullary cells present likewise a large number of concentric layers.

The partition-walls, taken from a tolerably old internode of Phytolacca decandra, appear to consist of very thin-walled cells; consequently they are in the very youngest state of development. By the action of iodine and sulphuric acid they instantly become blue; but they require the action of stronger sulphuric acid before that colour becomes dark. In other internodes of Phytolacca decandra, where medullary cells are found *with* and *without* pits or *tüpfel*, these reagents act in a very different way. The former remain lemon-yellow, whilst those without pits become of a beautiful blue.

In Asclepias syriaca all the medullary cells assume a fine blue colour when acted on by iodine and sulphuric acid (fig. 2, *e*, fig. 3).

The medullary cells of Clematis vitalba, when treated with iodine and sulphuric acid, present two layers, of which the interior becomes blue and the exterior yellow.

The medullary cells of a biennial branch of Tilia parvifolia, when treated with iodine and sulphuric acid, show a yellow rim outside, and a blue one inside. Here, therefore, two different layers exist. Pits are absent. Those of Taxus baccata, even in the older parts of the branches, instantly become blue on the application of iodine and sulphuric acid.

The medullary cells of Pinus sylvestris, after being digested for two days with strong hydrochloric acid, turn brown, and in some places violet. This indicates most distinctly the presence of protein. When the medullary cells of Hoya carnosa are treated in the same way, those with thin walls remain colourless, whilst the thick-walled assume a violet colour. Each of the former contains an internal utricle. Finally, in those of Tilia parvifolia taken from a young branch, the contents become violet by the action of these reagents, but the wall itself remains colourless, whilst in an annual branch of Clematis vitalba the whole of the medullary cells remain colourless. (Harting and Mulder.)

These observations, therefore, show that the medullary cells contain very different substances; when young, they

consist entirely of cellulose, whilst those which are incrusted—which takes place externally,—possess an exterior layer of intermediate woody matter (mixed with protein) without the additional inclosing layer which is found in the ligneous cells. In this respect, therefore, the incrusted medullary cells differ from these latter. Those of the elder tree are of a peculiar nature; whilst in Phytolacca we shall find that another substance is intermixed with cellulose.

The chemical nature of the pith cannot, therefore, be truly represented under any general formula; and yet this has been attempted.

Schaffner has analysed the pith of plants. (Ann. der Chem. und Pharm., April, 1844, p. 148.) He had taken it from different plants in the commencement of August, and exhausted it with water, alcohol, and ether. He found no nitrogen in any of his specimens. His results were as follows:—

	Pith of the Elder tree dried at 212° in the water bath.	Pith of Lappa major (Bardana.)	Pith of the Sun-flower.
C	43.85	45.45	44.90
H	6.40	6.13	6.60
O	49.75	48.42	48.50

	Of the Elder tree dried at 302°.	Of Bardana dried at 302°.
C	47.80	48.10
H	6.00	5.95
O	46.20	45.95

From these analyses he concludes, that the pith of plants consists of carbon and water, like starch and the fibres of wood; but these fibres are compound organs.

It is imposible, besides, that these analyses should be correct; for if we compare the results obtained from the pith of the Elder and Bardana, dried at 212°, with those from the same pith dried at 302°, they do not agree.

From the pith of the elder tree we have obtained a very different result. Taken in August from the second and from the fourth internode, counted from the top, digested

with water, alcohol, and ether, and dried at 302°, the results were:—

	2d Internode.	4th Internode.
C	49.40	49.17
H	6.05	5.97
O	44.55	44.86*

The ash amounted to about 2 per cent. We learn from these results that the pith of the elder tree in a somewhat advanced state of growth (see p. 442), is not one of the substances which consist of carbon, and of oxygen and hydrogen in the proportions to form water. It deserves a further investigation, and the more so, because it is a simple tissue.

The composition of the partition-walls, however (the young tissue of Phytolacca decandra, of which we mentioned the reaction before), has been found to agree with the formula $C^{24} H^{19} O^{19}$. After being digested in water, alcohol, and ether, and dried at 284°, they gave:—

			Atoms.	Calculated.
C	46.19	46.57	24	46.14
H	6.04	5.98	19	5.98
O	47.77	47.45	19	47.88*

They contained two per cent. of ash. This result shows that, although they still belong to those substances which become blue by the action of iodine and sulphuric acid, the strength of the acid which is necessary to produce this change, is in proportion to the changes which they have already undergone. It is no longer simply cellulose, but approaches in composition to the tissue of the seeds of Iris. (See p. 438.)

It is, therefore, far from true, that pith must be considered as one homogeneous tissue, which Schaffner appears to do. A mere microscopical examination of the pith of the elder tree, appears to be sufficient to show that such a view is untenable.

Q. Ligneous Cells.

The ligneous or woody cells are so important, that they

* Scheikund. Onderz., Deel III.

deserve special and detailed examination. Having subjected them to the action of various reagents, we believe we have been thus led to discoveries regarding them, which could not have been made in any other way. I shall begin by detailing these reactions.

The woody cells of the Pinus larix, taken from a branch with four annual rings, exhibit, on their transverse section, when moistened with iodine and sulphuric acid (4 parts acid to 1 of water), different reactions according to the age of the ring. In the innermost ring they present, on the transverse section, a thick swollen layer of a greenish yellow colour, surrounded by a brown rim. The ligneous cells which belong to the youngest or outermost layer present internally a blue film, around this a broad (swollen) rim of a greenish blue colour, and finally, a brown rim externally. On the longitudinal section they are green in the middle, and brownish yellow on the edges. (Fig. 20 and 21.) In Tilia parvifolia (fig. 22, 23, and 25), there is a thin brown layer (utricle?) in the middle,—a pale blue rim immediately around it, and a brown one outside; thus, there are only two layers besides the utricle. After half an hour the blue colour has disappeared, and is replaced by a brown one, which commences from without, and leaves a cross in the centre which is blue, and contains a small brown nucleus. Nearly the same phenomena are seen in the ligneous cells of the full-grown internodes of a one year's branch of a linden tree. In the spiral cells of the wood both the interior wall and the spire itself become blue. These spiral cells are scattered between the ligneous cells. In older wood these walls become brown, by the action of iodine and sulphuric acid, agreeing in this respect with the exterior layer of the ligneous cells (fig. 23).

The ligneous cells of Sambucus nigra, in a branch of this year, are coloured dark yellow by nitric acid, and become still darker on the addition of ammonia. In those of Asclepias syriaca (fig. 2), after being moistened with iodine and sulphuric acid, we observed around the woody cells a brown layer followed by a green one, and a blue one inside. The cells of the medullary rays appear green at the place where

they are cut through, (*a*,) and blue where they are open. Here, therefore, we have also a double layer, of which the interior is cellulose, but the exterior a peculiar substance exhibiting the same reaction that we observed in the exterior layer of the scaliform vessels (p. 432). The ligneous cells of a very young internode become entirely blue by the same reagents, without exhibiting any other substance except an internal utricle. We perceive nothing of an integument of the cell-wall turning brown, which, therefore, is undoubtedly produced from cellulose after the formation of the first cellular membrane (fig. 6). The blue colour which the substances that constitute the inside of older ligneous cells assume, also proves that other substances transude *through* the cell-wall; and, therefore, the latter must be a primary product consisting of cellulose.

In a young internode of Phytolacca decandra, we also observed that the whole transverse section of the ligneous cells becomes blue, and is readily dissolved by sulphuric acid, after being previously moistened with iodine. In an older internode the reactions are quite different. Here the transverse section presents four layers; first, a thin brown integument, which is sharply defined, on the outside, then follows a green swollen rim, after this a blue rim not distinctly separated from the former, and lastly a very thin brown rim on the inside. The latter we recognise as the internal utricle; and thus we find here again the same substances, three in number, that is, one more—the green one—than in the punctated vessels. It would appear, therefore, again, that this layer and the brown one are formed at the outside of the cell-wall, and are real incrustations, because the young ligneous cells present only a layer of cellulose, and the internal utricle.

Thin fragments of ligneous cells, when moistened with strong hydrochloric acid under cover, but with presence of air, for 48 hours, invariably assume the violet colour indicative of the presence of protein. Instances of this are given in fig. 24, representing slices of a biennial branch of Clematis vitalba, and Tilia parvifolia. In Hoya carnosa the change of colour had proceeded farther, the violet matter of Bourdois and Caventou

having been converted into humic acid. The youngest ligneous cells, however, had remained colourless, which shows that the albuminous matter is deposited there at a later period. In Pinus sylvestris the violet colour was very intense (fig. 17).

When ligneous cells are digested for 24 hours with a strong solution of potash at 140° Fahr., they become much swollen and are coloured more or less yellow or brown; such is the case with those of Pinus sylvestris and Hoya carnosa.

In a young internode of Clematis vitalba, the whole of the young ligneous cell, in which not a trace of incrustation has yet been found, is seen to become blue by the action of iodine and sulphuric acid (4 parts acid to 1 of water), without exhibiting even a trace of an exterior brown layer (fig. 30). This brown layer is present, however, in an older internode, and coated directly on the inside with a layer of cellulose, no intermediate woody matter being present. The latter, therefore, is subsequently secreted, in the third period of development, between the two former, the cuticle of the ligneous cells being deposited around the layer of cellulose in the second period. Both these substances are necessarily produced from substances existing in the contents of the cells, and secreted through the walls of the cellular layer; and thus it is unquestionably proved that this kind of ligneous cell is incrusted externally.

We have examined by different reagents the short ligneous cells of Clematis vitalba in a branch of two years old; they were completely developed (fig. 31–37). When treated with iodine and sulphuric acid, they present three different walls: an interior one, which becomes blue; an exterior one, brownish yellow; and an intermediate one, yellowish white. They are distinctly visible both on the transverse and on the longitudinal sections. On the transverse section the interior layer of cellulose is seen, of a pale green colour; around this a swollen rim, which, especially when strong sulphuric acid is used, exhibits five or more concentric layers, of which the exterior ones are brownish, whilst the colour of the interior passes insensibly into that of the blue internal membrane. These are surrounded on the outside with a thin brown layer (fig.

36). The transverse section of a full grown internode of a branch of a year old exhibits only the layer of cells that become brown, which immediately adjoins the light blue layer of cellulose (fig. 31, 32, 33, 34). As the older branch contains, between these two, five other layers, consisting of a substance different from both, these must have been deposited between them at a later period.

The pits which are present in these ligneous cells of Clematis, when fully developed, as well as those found in the medullary cells, belong to the two interior series, viz., the layer of cellulose and that of the intermediate woody matter, the third or exterior layer of the ligneous cells not being perforated. In the porous vessels, on the contrary, the exterior layer is perforated.

In a branch of two years old, the cells of the medullary rays become instantly blue by the action of iodine and sulphuric acid.

The ligneous cells in Taxus baccata are coloured by iodine and sulphuric acid in the following manner:—the transverse section presents an external yellow rim, beneath which is a fine blue followed up by spiral convolutions (fig. 19). Strong nitric acid makes the intermediate wall swell, and on the subsequent addition of an excess of ammonia this wall becomes of so dark a yellow colour, that no difference can any longer be perceived between the three layers. Strong sulphuric acid alone makes all three swell, but the intermediate one most,—so much so that it breaks through the exterior layer; and finally, this intermediate layer is dissolved whilst the two others are left. (Harting and Mulder.)

From all these observations it is evident, that the interior layer of the full grown ligneous cells is cellulose,—that around this a peculiar substance exists, interwoven with protein; whilst this again is inclosed by a third layer, of which the chemical nature differs from that of the others.

The *Cambium cells*, whose walls, according to Mohl, are a continuation of the exterior layer of the ligneous cells, and which should be considered as young cells of the latter kind, are affected by iodine and sulphuric acid in an entirely different

way. Those of Pinus sylvestris (fig. 16, *a*), became of a fine blue, whilst the exterior layer of the developed woody cells becomes brown as usual (*b*). The cambium cells, therefore, appear to consist entirely of cellulose; and, therefore, they not only have nothing in common with the exterior layer of the ligneous cells, but cambium, as long as it is unaltered, ought to bear a separate name. Not a trace of distinct layers is to be seen. We feel the more obliged to distinguish these cells from the real ligneous cells, because in Pinus the latter swell under the action of the reagents employed, so as to make the exterior layer burst, whilst the interior layers appear to contain but very little cellulose. We observe internally only a cruciform substance (remains of the internal utricle?) (fig. 16, *b*), and an expanded lead-coloured layer. If, therefore, in Pinus the cambium is converted into ligneous cells, the greater part of the cellulose must be replaced by another substance, and this again surrounded by others. There is, therefore, a marked difference between the structure of developed ligneous cells and that of cambium cells. Subsequently, however, the latter are converted into the former; and in this sense they may also bear the name of young ligneous cells.

From what has been said before (p. 204) it followed, that, starting from the hard stony fruits, we may assume the formula $C^{64}\,H^{44}\,O^{39}$, as representing the composition of the woody matter in a mass—that is, taking everything collectively that belongs to the ligneous cells, and leaving out of view the small quantity of nitrogen contained in it. If from this we subtract the formula of cellulose, $C^{24}\,H^{21}\,O^{21}$, the remaining formula for the incrusting matter is $C^{40}\,H^{23}\,O^{18}$, which, according to the observations just mentioned, represents the composition of two substances, viz., of the *exterior layer of the ligneous cells*, and of *their intermediate or real incrusting walls*, which internally passes into the third *layer, that of cellulose*. The internal utricle being so extremely thin, can have no influence on the result of the analysis.

The substances consisting of $C^{40}\,H^{23}\,O^{18}$, deserve to be particularly considered here, because Payen has on this subject

published observations (in his Mémoires sur les Développemens des Végétaux, p. 253), which are at variance with the experiments of Fromberg;* and because the formation of wood has such an important influence on the functions of plants.

I have taken the composition of the hard stone fruits as the basis of that of wood, because these fruits contain the woody matter in its highest state of condensation. The analyses by E. H. von Baumhauer, from which this result has been obtained, embraced the pericarps of Cocos nucifera, Cocos lapidea, Amygdalus persica, and Juglans regia.†

Payen has arrived at the same results from the investigation of hard kinds of wood, and the hard matter of pears.‡

Now, as it is established that the interior wall of the incrusted ligneous cells is a permanent one, and originally consists of cellulose, since it remains behind after the action

* Scheikund. Onderz., D. II., p. 222.

† Scheikund. Onderz., D. II., p. 208.

	Cocos nucifera:	Cocos lapidea.	
		I.	II.
C	52.99	52.27	52.15
H	5.88	5.87	5.73
O	41.13	41.86	41.12

Amygdalus Persica extracted with a strong solution of potash.

	I.	II.	III.
C	52.20	52.05	52.21
H	5.83	5.92	6.10
O	41.97	42.03	41.69

Juglans regia.

	I.	II.	III.	Atoms.	Calculated.
C	52.17	52.13	52.36	64	52.38
H	5.97	5.99	5.76	44	5.88
O	41.86	41.88	41.88	39	41.74

‡ Mém. quoted, sur les Développemens des Végétaux, p. 260 and 267.

	Wood of Ebony from		Hard matter in Pears.		
	St. Lucius.	Madagascar.	I.	II.	III.
C	52.90	52.85	52.04	52.97	52.61
H	6.07	6.00	6.21	6.22	5.67(?)
O	41.03	41.15	41.75	40.81	41.72

of potash,* we have great reason—hard woods and stone-fruits being so constant in their composition—to assume the empirical formula of hard wood as given before (p. 204), viz., $C^{64} H^{44} O^{39}$, and to represent the sum of the middle and exterior layers by the formula $C^{40} H^{28} O^{18}$, being the former, less the formula of cellulose.

The other less hard woods, however, are also worthy of consideration. They might contain a different incrusting matter, or the same matter and cellulose together in a different proportion. They contain cellulose, as has been shown by Payen and Von Baumhauer. The latter found, that when the woods of the laburnum, the elm, and the tulip tree, (Cytisus laburnum, Ulmus campestris, and Liriodendron tulipifera,) were treated with chlorine and then with potash, cellulose was left behind.† But the composition of the wood itself differs considerably from that of the hard woods,‡ and is even such that one would suppose the incrusting matter it contains to be different from that of the hard woods. This composition is also far from being constant; the proportion of carbon being smaller as compared with the hard woods. Thus the formula for the wood of Cytisus laburnum and Ulmus campestris is—

* Von Baumhauer found the following composition for Cocos nucifera, after being treated with potash and chlorine (Scheikund. Onderz., Deel II. p. 198).

			Atoms.	Calculated.
C	43.72	43.73	24	43.70
H	6.14	6.08	21	6.25
O	50.14	50.19	21	50.05

† Scheikund. Onderz., Deel II., p. 205.

	Wood of Cytisus laburnum.	Elm Tree Wood.	Tulip Wood.
C	44.65	43.81	44.12
H	6.09	6.03	6.11
O	49.26	50.16	49.77

‡ The result, obtained by Von Baumhauer from the analysis of these three kinds of wood, after being exhausted with alcohol, ether, hydrochloric acid, and water, was—

	Cytisus laburnum.	Elm Wood.	Tulip Wood.
C	49.11	49.52	47.76
H	5.97	5.98	5.89
O	44.92	44.50	46.35

$C^{64}\ H^{47}\ O^{45}$*

which differs by $H^3\ O^6$ from wood of the harder kinds. The formula representing the composition of the wood of Liriodendron tulipifera is $C^{64}\ H^{48}\ O^{47}$,† differing from that of the harder kinds of wood by $H^4\ O^8$.

Here, however, we must bear in mind, that this formula expresses the composition of a mixture of four different substances, one of which, albumen, is by no means to be overlooked. In proof of this, we need only to take saw-dust, from any kind of wood, and pour upon it first nitric acid and then ammonia, and we shall invariably obtain an orange-coloured jelly (see Scheikund. Onderz. Deel III.), which owes its intense colour to the presence of xantho-proteate of ammonia.

The above formulæ, therefore, represent the composition of a very variable mixture of four different substances, which, so far as we are now acquainted with them, are the same in all, at least in the softer kinds of wood. In full grown ligneous cells, the exterior layer, after having acquired a certain thickness, no longer increases to any perceptible amount; the interior layer, consisting of cellulose, also appears to retain its original extent; but the intermediate layer continues growing, and forces the inner one forward, so as to diminish the aperture of the cell. With the increase of the intermediate layer in thickness, the proportion of protein, which is deposited chiefly in this layer, also increases.

The relative quantities of protein and intermediate woody matter are, however, not the same in different kinds of wood, as may be inferred simply from the change of colour which various kinds of saw-dust undergo under the influence of nitric acid and ammonia. The colour of fir wood becomes darker than that of oak wood, although the latter contains

*

	Atoms.	Calculated.
C	64	49.02
H	47	5.70
O	45	45.28

†

	Atoms.	Calculated.
C	64	47.81
H	48	5.87
O	47	46.32

much more of the intermediate woody matter than the former.

Although, therefore, the analyses of wood that have been made are of much importance, in the greater part of them the determination of the nitrogen is wanting, which is to indicate the proportion of protein that is included, if not wholly, at least for the greater part, in the intermediate layer. The determinations of the composition of wood which have been made by Chevandier (Annales de Ch. et de Phys., Fevr. 1844, p. 129), are the only ones of value as regards this point. He found, as we have mentioned before, in different sorts of wood, an equal proportion of carbon and hydrogen, but at the same time the proportion of nitrogen varied between 0.67 and 1.52 per cent., which represents a quantity of protein amounting to not less than from 1-24 to 1-11 of the wood in weight.

We shall take one of Chevandier's analyses, for the purpose of calculating from it the ratio between the atoms of carbon, hydrogen, and oxygen, as contained in the mixture of the substance of the exterior layer and the intermediate woody matter. We shall select for this purpose his analysis of Beech wood, p. 143—the equivalent of carbon being taken at 75, that of hydrogen at 12.5.

	Found.	Proportion of atoms.
C	49.71	6630
H	5.98	4785
N	0.88	5
O	43.43	4343

Considering now that there are present here four different substances, viz.: protein, cellulose, exterior woody matter, and intermediate woody matter, we obtain—

	C	H	N	O
	6630	4785	5	4343
Protein,	40	31	5	12
	6590	4754	0	4331
Cellulose,	24	21		21
	6566	4733		4310

By reducing these remainders in uniform proportion, we obtain for the composition of the exterior and intermediate woody matters:—

C	40
H	29
O	26

Of this mixture the exterior layer may constitute from 1-5th to 1-10th, the rest is the woody matter with which the cell-wall is incrusted.

I bring these details forward, less as purely scientific facts, than for the purpose of pointing out the impropriety of calling the whole substance of the ligneous cells woody matter, and of always considering carbon and water as the sole constituents of *woody fibre* (?)

There is still one point, however, worthy of our attention. We have seen, (p. 424) that the composition of the woody matter of the spiral threads, freed from protein, cellulose, and the exterior layer of the ligneous cells, is $C^{40}H^{28}O^{26}$, whilst the formula derived from Chevandier's experiments, as indicative of the composition of that woody matter mixed with the substance of the exterior layer, but free from protein and cellulose, is $C^{40}H^{29}O^{26}$. These results, obtained from experiments of two entirely distinct parties, deserve attention, and render it probable that the intermediate woody matter and that of the exterior layer of the woody cells have the same composition in the hundred parts, although it is obvious that the former may be a compound body.

This result has, however, been obtained only from the woody matter of the spiral threads of Agave and the Beech tree. The exterior and intermediate layers of the hard stone fruits, taken together, give, as we have seen, a different result, namely, $C^{40}H^{32}O^{18}$; but all of these contain ulmin, to which their brownish colour is owing. I would, therefore, be inclined to state at present, that the intermediate woody matter is not a compound body; that the substance of the exterior layer of the ligneous cells is isomeric with that of the intermediate layer; that the latter is in excess in soft or

young wood ; that both in the hard stone fruits and in the hard woods the same substance is present, but that its composition in the two latter differs from its composition in soft wood, by a quantity of ulmin which the former contains.

This is all we at present know with regard to the woody matter. The subject is still far from being exhausted, as we may see, and it will be difficult to complete the investigation. Payen's experiments have brought us no nearer to a correct knowledge of it ; they have only made it more complicated. Mere products of decomposition can here give us no light whatever.

What we have now said may be looked on as the continuation of the views given at p. 204, which were written before the microscopical investigations, just mentioned, were made. I shall only add this single remark, that the formation of wood from dextrin is one abundant source of the oxygen disengaged by plants. Thus the composition of the woody matter of the spiral threads of Agave, or of that of the exterior and intermediate layers of the ligneous cells, as determined by Chevandier, shows that the conversion of 4 equivalents of dextrin into those substances must give rise to the disengagement of 2 equivalents of oxygen.

From 4 equivalents of dextrin, ...	$C^{40}H^{40}O^{40}$
Take woody matter, ...	$C^{40}H^{28}O^{26}$
And there remains, ...	$H^{12}O^{14}$
From this take 12 equivalents of water,	$H^{12}O^{12}$
And 2 of oxygen are left, ...	O^{2}

The quantity of oxygen disengaged is greater during the formation of the mixture of substances, the entire formula of which we derived from the hard kinds of wood,—a mixture which certainly occurs in different kinds of wood in greater or less proportion,—because in all kinds the proportion of hydrogen is tolerably constant (5.8—5.9—6.0), while that of carbon varies, although not insensibly, from 48 to 52.5 per cent.

From 4 equivalents of dextrin, ...	$C^{40} H^{40} O^{40}$
Take 1 equivalent of the mixed woody matter,	$C^{40} H^{23} O^{18}$
	$H^{17} O^{22}$
And 17 equivalents of water, ...	$H^{17} O^{17}$
And 5 of oxygen remain, ...	O^{5}

The formation of wood, therefore, gives rise to a constant disengagement of oxygen by plants.

I shall now proceed to mention Payen's experiments. He thought (see his Mémoir, p. 271), that he should be able to dissolve the incrusting matters from wood unchanged by a strong ley of soda or potash—after having previously exhausted the wood with water, alcohol, acid, and a weak solution of alkali. He further thought he should precipitate them from the alkaline solution by hydrochloric acid. After the precipitate had been washed with water, it was dried and exhausted with alcohol. The alcohol deposited a powdery substance, and left a similar one behind on evaporation. The alcoholic residue was exhausted with ether, in which one part dissolved, whilst another part remained insoluble. By ammonia it was also separated into two parts, the one being soluble, the other not. He distinguished these various products by the following names: *Lignose*, which is insoluble in water, alcohol, ether, and ammonia, but soluble in potash and soda;* *Lignone*, insoluble in water, alcohol, and ether, but soluble in ammonia, potash, and soda;† *Lignin*, insoluble in water and ether, but soluble in alcohol, ammonia, potash, and soda;‡ *Lignirose*, which is sparingly soluble in water, but readily soluble in alcohol, ether, ammonia, potash, and soda.

However beautiful this may appear, it is, alas! of no value. For, in the first place, the strong alkaline solution with which the wood is treated, dissolves part of the cellulose, which is precipitated by the acid; and, secondly, we have to deal with a series of products arising from the action of the alkali on the

* C	46.10	† C	50.10	‡ C	62.25
H	6.09	H	5.82	H	5.93
O	47.81	O	44.08	O	31.82

incrusting matter, which we before called *intermediate woody matter*, whilst it is likely that not one of these products exists as such in the wood; and besides there are found amongst them humic substances into which the intermediate woody matter is so readily converted.

The incorrectness of Payen's results, at least of the conclusions which he has drawn from his experiments, has been most evidently proved by an extensive investigation that has been made by Fromberg.*

He digested elm tree wood (Ulmus campestris) for a number of days, with a very weak solution of potash (5 parts of caustic potash to 750 of water); and repeated this process several times. The colour of the liquids was always brown, proving that a change had really taken place in the organic matter. From each of the solutions successively obtained, he threw down a precipitate by acids, which, having been digested with alcohol and ether, varied in composition between—

C	64.12	and	C	57.83
H	6.15		H	5.93
O	29.73		O	36.24

The wood left behind, after being so treated for a great many days, gave—

C	50.10
H	6.17
O	43.73

—that is, nearly the original composition unchanged. The wood was afterwards digested repeatedly, each time for several days, with a stronger solution of potash (10 parts to 750 of water); the liquid was now less dark in colour than the weaker solution formerly employed. By the addition of an acid a precipitate could be again obtained from this liquid. By increasing the proportions of potash, Fromberg obtained precipitates which were now more gelatinous and far less deeply coloured, and which gave, after being digested with alcohol, compositions, varying between—

* Scheikund. Onderz. Deel II., p. 222.

C	57.92	and	C	50.02
H	6.37		H	6.10
O	35.71		O	43.88

—in these, therefore, the proportion of carbon was again variable. The composition of the remaining wood was now—

C	48.05
H	5.96
O	45.99

It appears most clearly that the last precipitate was obtained from a solution of cellulose and incrusting matter, mixed together and thrown down in nearly the same proportions in which they are originally contained in the wood.

The legitimate conclusion, therefore, to be drawn from these results is evident. The weak potash solution had not only dissolved substances from the wood, but had induced in them a chemical change. The alcohol with which the wood had been treated, remained colourless; but that with which the precipitates had been digested had taken up a brown substance, which, therefore, was evidently a product of decomposition, formed from the intermediate woody matter by the action of the alkali. By using strong potash,—after the substances of the wood, decomposable by alkalies, were removed,—cellulose and the intermediate woody matter were dissolved almost in the same proportions in which they existed in the original wood.

For this reason, it is very possible that the incrusting matter of elm tree wood is not a simple but a compound body, although in all the incrusted ligneous cells it appeared simple in the form of the intermediate layer; but we are, as yet, entirely ignorant of its composition, which is certainly different from what Payen has stated it to be. He has analysed products of decomposition, cellulose, unchanged wood, &c., and to mixtures of these substances he has given the names we have mentioned. Nor has he taken into account the substance which constitutes the exterior layer of the ligneous cells, which substance differs in all its properties from the intermediate woody matter.

By treating elm-tree wood with a weak solution of potash (20 parts to 600 of water) in the cold, Fromberg obtained again a coloured solution, which was even darker in colour than that prepared with the aid of heat, which, however, may have been partly due to the greater strength of the liquid. By repeating this digestion, and adding acetic acid to the solution, he obtained precipitates which were purified with alcohol and ether, to which they did not communicate any colour, differing in this respect from the precipitates separated from the solutions that were obtained at an elevated temperature. They gave—

C	55.48	51.90	49.12
H	5.76	6.35	6.17
O	38.76	41.75	44.71

The remaining wood yielded, on analysis—

C	51.81
H	6.36
O	41.83

After this treatment with a cold potash ley, he digested the wood with two successive warm solutions of potash, (20 parts to 750 of water) and, finally, with a solution of 50 parts of potash to 400 of water. The precipitates which were now produced, gave a brown colour to alcohol, and after being exhausted with it, they yielded—

	I.	II.	III.
C	61.08	56.59	49.44
H	6.18	6.23	6.16
O	32.74	37.18	44.40

whilst the wood that now remained gave—

C	50.41	50.60
H	6.32	6.11
O	43.27	43.29

—which is, indeed, almost the composition of unchanged wood, the only difference being that the proportions of carbon and hydrogen are a little higher in the latter.

The precipitates I., II., and III. appear to be considerably

different from those obtained by the cold potash ley. In No. III. we find the composition of the wood itself; No. II. is a mixture of Nos. I. and III., whilst No. I. is a new product of decomposition.

The results which Fromberg obtained from laburnum and tulip wood, were different from those given by elm-tree wood. This indicates a variableness in the sum of the constituents of the two exterior layers, which, although denied by Payen, does not admit of any doubt, and may very naturally be expected where either the species or the age of the wood is different, and may, perhaps, also be owing to a change in the intermediate woody matter itself.*

From these experiments, Fromberg arrives at the conclusion that the incrusting matter consists of various layers of a different chemical and physical nature; that some layers having more mutual adhesion, are more readily dissolved by a cold and strong, than by a weak though hot potash solution. One of the precipitates he obtained from the wood of the laburnum had precisely the same composition as ulmic acid (p. 154); whilst by the influence of sulphuric acid, either alone or assisted by that of potash, he obtained a series of products, of which the composition does not, as yet, enable us to form any definite idea of the incrusting matter of wood, because either slight differences in the degree of strength of the reagents, or a difference in the kind of wood, has always the effect of giving rise to different products.†

* Ligno-sulphuric acid, which is, no doubt, a mixture of different substances, has of late been investigated by Blondeau (Erdmann's und Marchand's Journal, No. 15, 1844, p. 429). That prepared from cotton wool cannot possibly be the same substance as that which is obtained from wood. (See p. 414.) That from cotton wool contains the constituents of cellulose; that from wood has some others in addition.

When saw-dust, moistened with sulphuric acid and washed with water and ammonia, is examined with the microscope, it exhibits very distinct laminæ, consisting of the exterior layers of the ligneous cells. They were, however, so much intermixed with ulmic substances, which could not be separated from them, that I am compelled, as yet, to give up the attempt to purify them further.

† Harting thinks (Scheikund. Onderz. Deel III.) that the intermediate layer of the woody cells contains pectic acid, and that the exterior layer corresponds

R. The Parenchymatic Cells of the Epidermis.

These cells exhibit reactions similar to those of cellulose. Those of Hoya carnosa, taken either from the second or fourth internode, become dark blue when moistened with iodine and sulphuric acid. (Fig. 1 B *c*.) Those in the seventh internode become green, owing to the simultaneous presence of substances that respectively turn blue and yellow. The cortical fibres which are situated here, become very conspicuous by the light blue colour which they assume (*d*). Internally these cells exhibit a brownish yellow membrane, but externally they appear not to have any integument of their own.

They dissolve in strong sulphuric acid. Those in the fourth internode are not coloured by strong nitric acid, even after the addition of an excess of ammonia. (Fig. 1 A *c*.) They do not, therefore, contain any protein. The epidermic cells of Sambucus nigra are not changed by nitric acid, but by iodine and sulphuric acid they become blue.

Those of Clematis vitalba become also of a fine blue inside, and are inflated by the action of the two latter reagents; at the same time they exhibit a tolerably thick, brown integument, which is considerably thicker than that in which those ligneous cells, which are somewhat older, are enveloped, though in other particulars it seems to be of the same nature as the exterior woody matter.

The epidermic cells of Tilia europæa become instantly blue when moistened with iodine and sulphuric acid. (Harting and Mulder.)

S. The Fibrous Cells of the Bark.

The fibrous cells of the bark of Agave americana, when moistened with sulphuric acid (3 parts to 1 part of water),

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with the cuticle of plants or with cork, but with this I do not agree. I have not, however, had the pleasure of making my esteemed colleague participate in my opinion.

become greenish brown, and swell much, so that the cavity entirely disappears. When the action has lasted one hour, the whole of the interior is dissolved and the exterior layer is left, thus showing that the latter is essentially different from the interior part with which it is in contact. Even after the action of sulphuric acid has been continued for forty-eight hours, the exterior layer is left unchanged.*

When moistened with tincture of iodine, and subsequently with sulphuric acid (3 parts to 1 part of water), these cells become brown. On the addition of strong sulphuric acid, they assume the green colour of bile (fig. 40 B), whilst all merenchymatic cells become blue,—with a brown, very distinct line of enclosure, and a similar rim in the transverse section. When the action of the acid has continued for some time, the bile-like colour of the intermediate cell-wall becomes more bluish, exhibits concentric layers, and, finally, turns brown and is dissolved, leaving behind only the exterior layer which at first became brown, and which still exists even after forty-eight hours' action. (Fig. 40 D.)

This reaction reminds us of the three layers of the cell-walls distinguished by Hartig (Beiträge zur Entwickelungsgeschichte der Pflanzen), viz., the Ptychode, the Astate, and the Eustate. There is no doubt that a difference exists between them. The reaction of iodine and sulphuric acid upon the middle wall shows that some, though comparatively little, cellulose exists there. It is intermixed with a substance which becomes brown by the action of sulphuric acid—a substance producing ulmin; this, therefore, is intermediate woody matter, whilst the exterior layer of the cell-wall, and the thin interior layer which also assumes a brown colour, are affected in the same way as the exterior matter of woody cells, with which, therefore, they may probably be identical.

The contents of the fibrous cells of the bark in a very young

* The vapour of Bromine colours the merenchymatic cells and fibrous cells of the bark in Agave yellow. By this means the boundaries of the latter in the transverse section are rendered very distinct.

Agave become brown by the action of iodine and sulphuric acid (4 parts to 1 part of water), while the cells themselves appear surrounded with a blue line. (Fig. 69 and fig. 38.) When the leaves are older, the same reagents render the latter colour a little more greenish (see preceding page), which shows that the cellular matter in the inside undergoes gradual change. (Fig. 39.)

The bundles of fibres in the bark of Phormium tenax, when moistened with iodine and sulphuric acid, become greenish; by stronger acid they are dissolved. No exterior wall is left here, as was the case in Agave. The little groups of fibrous cells of the bark in the second internode of Hoya carnosa, when treated with the same reagents, are very much swollen, become of a light blue colour, and present no exterior brown integument. (Fig. 1 B *d*.) Those in the seventh internode assume a still lighter blue colour. Nitric acid does not change their colour, nor that of those in the fourth internode. (Fig. 1 A *d*.) By strong sulphuric acid they are dissolved.

The fibrous cells of the bark in a branch of Sambucus nigra, of the first year's growth, become yellow by the action of nitric acid, and much more so when an excess of ammonia is afterwards added. Iodine and sulphuric acid makes them blue. The same takes place in Asclepias syriaca, where even in the young internodes not a trace can be seen of the integument of these cells, which becomes brown by this reaction. Like the membrane of the ligneous cells, therefore, this integument is of later origin, and must be formed from the substance that has transuded through the layer of cellulose.

Those of Tilia parvifolia become, under the same reagents, light blue, swollen, and present externally a brown wall, and a little brown point in the centre, formed by the contraction of a membrane (the internal utricle?) in consequence of the swelling. The light blue expanded wall exhibits in several places concentric rings. The latter become more and more expanded, and thus finally cause the brown exterior layer to burst.

The thin brown wall which we have observed in these fibrous cells, after the application of the reagents mentioned, was not found by us in Clematis vitalba, in which, however, the fibre of the bark became light blue, but we saw it again in Cicas revoluta. There is on the inside of this brown wall, a thick, swollen middle part, of a greenish yellow colour, having a small blue cross in the centre, produced by the contraction of the interior membrane of cellulose. These cells swell very much under the action of strong nitric acid.

The fibrous cells of the bark of Clematis vitalba contain protein, for we saw them assume a rose-red colour after they had been digested with strong hydrochloric acid for forty-eight hours in the air. (Harting and Mulder.)

The same cells in Agave americana, exhausted with water, alcohol, and ether, and dried at 266°, gave, on analysis, the following results:—

C	46.93	47.02
H	6.05	6.18
O and N	47.02	46.80*

They leave 2½ per cent. of ash, which, on being moistened with sulphuric acid, shows almost no effervescence.

It would be useless to express these proportions by a formula, because these cells contain much cellulose, some protein, some intermediate woody matter, and, finally, that substance which we called exterior matter of woody cells. On being digested with strong acetic acid, these fibrous cells lost all their inorganic constituents and the protein, and gave, on analysis—

C	46.32
H	6.01
O	47.67†

There is, therefore, no real chemical difference between the fibrous cells of the bark and the ligneous cells.

* Scheikund. Onderz. Deel III.

† Ibid.

T. The Collenchyme.

The collenchyme, or that part of the cellular tissue which in some plants is situated immediately below the epidermis, is, in Phytolacca decandra, affected by nitric acid (fig. 12 and 13), in a manner different from the parenchyme in the same plant. A transverse section of the third internode, counted from the top, is not changed in colour by nitric acid, not even after the addition of ammonia, whilst the contents of the cell become yellow. Neither is any colour produced in the rhomboïdal shaped substances that arise from the local incrustation of the cell-wall, and which become distinctly circumscribed, and assume the appearance of segments of a circle, after the action of nitric acid. Hence it is evident that this substance is different from cellulose.

The collenchyme of Opuntia braziliensis is not coloured by nitric acid, not even after the addition of an excess of ammonia, any more than the parenchyme of this plant. By strong sulphuric acid the walls of the collenchymatic cells become much swollen; their cellular appearance is even entirely lost, like that of the parenchymatic cells, but later. A strong solution of potash effects the same expansion and disappearance of the cell-walls. Payen's opinion was, that they consist in a great part of pectate of lime. They certainly show other properties than pure cellulose does; plants do not, however, contain pectic acid *as such*, but a substance, which under various circumstances can become gelatinous, viz., pectose. The reaction effected by tincture of iodine with sulphuric acid (4 parts to 1 part of water), fig. 14 *b*, has completely convinced us that these walls, which are very thick even in the natural state, consist not of pectose alone, but of an intimate combination of pectose and cellulose. The latter is changed in colour by these reagents, but not the former, and we saw that the collenchyme, like the parenchyme, became instantly of a very fine blue, without presenting anything heterogeneous, or any different layers. We learn from the preparation of pectic acid, that pectose is intimately mixed up with cellulose. (Scheikund. Onderz. Deel III.)

The transverse section of the collenchymatic cells, of which the walls are very thick and swollen, presents undulated concentric circles, a fact which indicates some difference between the layers of pectose and cellulose. The exterior wall of the cells is entirely colourless, so that the cells are separated from each other by a transparent uncoloured wall. It is probable that this wall is nothing else than pectose. This pectose, however, also penetrates partly into the wall of cellulose, and forms with it layers that are more or less alternating.

The collenchyme of Sambucus nigra is very much swollen by strong nitric acid, but is not changed by the subsequent addition of ammonia. Tincture of iodine with sulphuric acid renders it blue. If, therefore, pectose be present here, it is diffused through the cellulose.

In very young branches of Tilia parvifolia, the collenchyme is not coloured yellow by nitric acid. By iodine and sulphuric acid it becomes of a dark blue, without giving any indication of the presence of different substances in the cell-wall. (Harting and Mulder.)

The cellular membrane of the collenchyme appears, therefore, to consist of pectose interwoven with cellulose.

U. The Cuticle.

It has long been known that the epidermis of plants consists of a layer of cells. Ad. Brongniart, however, has asserted, that by the process of maceration a thin membrane could be separated from the surface of plants, which was either homogeneous or granular, and differed from the walls of the cells in the epidermis. According to Brongniart, this membrane covers almost the entire plant; botanists call it cuticle. It has been examined by many philosophers, and last of all by Mohl.*

This cuticle is coloured yellow by iodine, sometimes even brown, so that when the transverse section of an epidermis

* Linnaea, Bd. VI. Heft 5, S. 401.

is moistened with this tincture, the walls of the cells of the epidermis become of a light brown, whilst the outermost layer (the cuticle) assumes a dark yellow or brown colour. If, after being coloured by iodine, it is laid in sulphuric acid, the former parts assume a fine indigo colour, whilst the cuticle, coloured by iodine, remains unchanged.

Organs which are not covered with a coriaceous epidermis, have generally a very thin cuticle, and hence, when coloured by iodine, they show only a very thin brown layer.

The cuticle is a coherent, smooth membrane, having either parallel or irregularly divided linear projections on its surface. On this surface, however, these parts or projections are not distinctly defined as on the covering of the epidermic cells, but the whole has the appearance of a continuous membrane. Sometimes the cuticle is very large, so that it covers the surface in an undulated, or even in a plicated manner; sometimes even from that cause it appears as if covered externally with little granules. We may, therefore, consider the cuticle as a product secreted by the exterior layer of the cells of the epidermis (Mohl).

The cuticle or the layer which covers the cells of the epidermis is of an entirely peculiar character, and the substance of which it consists is, as shown by all the reagents employed, in no respect similar to that of the cells of the epidermis. In Aloë lingua, this cuticle, with the warts on its surface, is not dissolved, nor even changed in colour by the action of strong sulphuric acid. It remains unchanged even after having lain in strong sulphuric acid for four days. Neither is it in any degree dissolved by fuming nitric acid (fig. 8). When moistened with iodine and then with sulphuric acid, it undergoes no other change than that it is coloured brown by the iodine. Not a trace of layers is to be seen.

Aqua regia, hydrochloric acid, and strong phosphoric acid, have no perceptible influence upon the cuticle.

The cuticle of Aloë lingua, when acted upon either by strong sulphuric acid alone, or after the previous application of iodine, or also by phosphoric acid, gives way in several places from the cells of the epidermis being dissolved, and

then a little membrane appears, which presents nothing resembling cellular structure; nothing, in a word, which can be in any way distinguished even by a magnifying power of 300. The cuticle of the very youngest leaves of Agave americana, that are still very far from their state of complete development, presents exactly the same reaction as that of the old leaves.

All that has been said here of the cuticle of Aloë lingua, we found to be exactly true with regard to that of Agave americana (fig. 69, 70, 71, 72). In the latter, however, we saw, besides the exterior layer of the cuticle, some portions of it which pass inwards and surround the exterior half of the cells of the epidermis. These consist of the same substance as the exterior layer, which is covered with warts, and exhibits exactly the same reaction.

By strong nitric acid the cuticle is instantly coloured yellow, which colour becomes much more intense on the addition of an excess of ammonia.

By sulphuric acid (3 parts to 1 of water) the cuticle is neither changed in colour nor dissolved; after the action of an hour it has become yellow, but after 48 hours no further change has taken place; it has not even become swollen.

The cuticle in Agave becomes brown by the application of iodine, followed by that of sulphuric acid (3 parts to 1 of water), and its inferior boundary is rendered distinctly visible. On the subsequent addition of strong sulphuric acid, the cuticle retains its colour, but the cells of the epidermis, which are not covered on their upper face by the cuticle, and those of the merenchyme, turn blue. It is this reaction especially which distinctly shows the difference between the nature of the substances of which the cells of the epidermis and the cuticle severally consist. After 48 hours the cells of the epidermis are dissolved, but the cuticle is left appearing either denticular, or cut out below in a semicircular manner.

The cuticle of Phormium tenax becomes yellow on the application of strong nitric acid, and brownish yellow by subsequently adding ammonia in excess. By iodine and sulphuric acid it is coloured brown (fig. 74).

The way in which the cuticle is disposed shows clearly that the substances of which it consists are secreted by the exterior layer of the cells of the epidermis. It envelopes the exterior surface of this layer in the shape of little cylinders, and therefore its substance has been secreted towards the outside from the contents of the cells of the epidermis, through their walls.

The cuticle of Hoya carnosa is affected by nitric acid and ammonia, by iodine and sulphuric acid, in the same manner as has been mentioned of others (fig. 1, A and B, *aa*). The same applies to that of Sambucus nigra.

In the anthers of Gladiolus pittacinus the cuticle, when acted upon by sulphuric acid, is loosened and hangs down in large fragments without any cells, which, after a previous application of iodine, have a yellow colour; whilst the layer immediately under it becomes blue (Harting and Mulder).

The cuticle might, perhaps, be obtained in a pure state, by loosening it from the plant by soaking in sulphuric acid. We have analysed it, united to a layer of epidermic cells, taken from Phytolacca decandra and Agave americana; in that of the latter, the proportion of cellulose derived from the epidermic cells can be but small. They were both purified by digestion in water, alcohol, and ether, and dried at 266°. Those of Phytolacca left 2 per cent., and those of Agave more than 4 per cent. of ash.

	Cuticle with Epidermic Cells from Phytolacca decandra.		Cuticle with Epidermic Cells from Agave americana.	
C	52.90	52.70	63.51	63.28
H	6.79	6.80	8.82	8.89
O N	40.31	40.50*	27.67	27.83†

These results, though apparently very different, are not really so, as far as the cuticular substance itself is concerned. In the cuticle of Phytolacca the proportion of epidermic cells (cellulose), mixed with the cuticular substance, was much larger than in that of Agave. Deducting this cellular matter from both, a substance almost identical in composition is

* Scheikund. Onderz., Deel III.
† Ibid.

left, although even that from Agave is not to be considered entirely free from cellulose.

We have attempted in vain to separate the cuticle in a pure state by soaking in sulphuric acid. Although it is not dissolved even in Nordhausen (fuming) sulphuric acid, by which every thing else adhering to it is dissolved, but in which the cuticle retains even its form completely—still it is coloured even by ordinary sulphuric acid (the bi-hydrate), too much coloured at least for being fit for an ultimate analysis. This colouring becomes much more manifest on subsequent treatment with ammonia. This blank cannot, therefore, be filled up at present; but it is likely that a certain strength of sulphuric acid may exist which will dissolve the other substances, and leave the cuticle behind.

X. The Epidermis.

In plants of a very simple structure, the epidermis is not different from the tissue immediately below it, but in plants which are more composite this difference is very great. It is covered by the cuticle, is colourless and transparent, and in some plants it can be separated with ease, in others only after the tissue underneath has been thoroughly soaked.

The cells of which the epidermis consists are mostly very large, tabular, regular, often tetragonal, or hexagonal, sometimes irregular, on a horizontal section. They are very solid, and are connected with the tissue underneath, without any intervening space. The under wall is much thinner than that which is exposed to the air.

It appears to be a very natural assumption, that an entirely peculiar series of cells should be composed of entirely peculiar substances. The case here, however, is more simple. When the greater part of the surface of a series of ordinary cells is withdrawn from the influence of the circulating fluids, no new cells are developed; and hence, by the increase of the underlying part they must become extended, flat, and tabular;—in a word, as only the inferior surface of the epidermic cells is in contact with the fluid of the cells, it is probable

that it has precisely the same origin as the cells underneath; and consequently, that both the cuticle and the underlying cells consist of the same substances. Hence it is that sometimes only one series of epidermic cells is found.

No analogy whatever, therefore, exists between the epidermis and cuticle of plants, and the epidermis of animals.

The *cells of the epidermis*, from which we naturally distinguish the cuticle, have exactly the same properties as the parenchymatic cells, mentioned before (p. 417). In Aloë lingua (fig. 8) they are dissolved by strong sulphuric acid without undergoing any change in colour. When tincture of iodine has been previously applied, they exhibit the same fine blue colour as the merenchymatic cells, and are rapidly dissolved. Neither here nor in other plants do they offer any more resistance to the action of strong sulphuric acid, than the merenchymatic cells do. They are dissolved by strong phosphoric acid; and after the application of tincture of iodine, they exhibit the colour of iodide of starch.*

In places where the cuticle has been loosened by the action of iodine and sulphuric acid, the exterior layer of the epidermic cells which are still entire, has also a blue colour. The existence of the exterior layer of the epidermic cells is, therefore, entirely independent of that of the cuticle.

The epidermic cells of Agave americana (fig. 69) exhibit the same reactions as those of Aloë lingua. The cells of the epidermis in Agave, however, resist the action of sulphuric acid (4 parts to 1 of water) until the merenchymatic cells are all dissolved, and do not themselves dissolve till later. Here, therefore, they are of a somewhat more solid structure than the merenchymatic cells, though they both consist of the same substance. When moistened with nitric acid, and

* Aqua regia, nitric acid, hydrochloric acid, and diluted sulphuric acid, have no perceptible action upon the epidermic cells—only the internal utricle, which can be very distinctly seen here, becomes prominent on the application of the latter acids. This takes place as well in old epidermic cells, viz., those in the summit of an old leaf,—as in very young ones taken from leaves before their development (see p. 418).

then with ammonia, they present no trace of xantho-proteate of ammonia.

The epidermic cells in Opuntia tuna become so much swollen by the action of sulphuric acid, that they soon cease to be recognisable as cells. In this they exhibit the same properties as the collenchyme and parenchyme of this plant, of which the cell-wall seems to contain pectose (Harting and Mulder).

Y. The Hairs of Plants.

The hairs of plants may be viewed in two different lights —as regards their origin and their chemical properties. Some consist of epidermic cells covered with a thick layer of cuticular matter. Of this kind are those found in Opuntia microdasys. By iodine and sulphuric acid their external surface does not become blue, but brown. We have not observed their internal appearance (fig. 75). Externally they are entirely analogous to the cuticular substance.

Different from this kind of hairs are those which have either a very thin layer of cuticular matter, or none at all, such as we find in Salvia argentea. These are multi-cellular, most generally without any contents, and their wall has a thickness of 0.0007 of a millemeter. By nitric acid the wall becomes neither swollen nor changed in colour. On the subsequent addition of ammonia in excess no yellow colour whatever appears. They are not affected by potash. Iodine colours them very slightly yellow, and when sulphuric acid is then added they become violet, with different gradations of lighter and darker tint, some of the extremities being partly, others completely blue. From the drier nature of these hairs, the penetration of iodine is rendered more difficult, which is the cause of this difference. They appear, therefore, to consist entirely of cellulose.

Cotton exhibits exactly the same reactions. The thickness of its wall is 0.002 of a millemeter, and both its reactions and composition are in all respects the same as those of cellulose (see *Cell-wall*, p. 413). (Harting and Mulder.)

Z. Thorns or Spines.

The internal tissue of thorns or spines is, as far as we have examined them, similar to that of the ligneous cells. In Cirsium triacantha, they consist of thick-walled cells, the walls of which have a thickness of 0.0077 of a millemeter. They are covered with cuticular and epidermic cells. Such of these cells as are situated internally, are coloured brown on the surface by the action of iodine and sulphuric acid; then follows a bluish, swollen wall, and in the inside we perceive a dark brown, granular membrane (internal utricle?). (Harting and Mulder.)

When dried at 275°, and digested with alcohol, ether and water, they have the following composition:—

C	49.44
H	5.99
O N	44.57*

—that is, the same as that of wood. They leave above one per cent. of ash.

AA. The Cork Tissue.

This tissue, which exists in a great number of plants, deserves particular attention. It is very beautifully seen in Opuntia tuna. Iodine with sulphuric acid (4 parts to 1 part of water), which imparts a fine blue colour to the collenchyme and parenchyme, leaves the cork cells entirely unchanged; only after 24 hours they have become brown (fig. 14, *a*). This proves, therefore, that we have here a peculiar tissue, which cannot be derived from cellulose, and is entirely different from wood.

The cork cells in Hoya carnosa are not changed by sulphuric acid; they only become brown if they have been previously moistened with tincture of iodine.

In this reaction, they behave themselves in the same manner as the cuticle, and this observation seems to accord with the opinion, that this cork tissue is formed in the same man-

* Scheikund. Onderz. Deel III.

ner as the cuticle, of which it appears to be a repetition. This conclusion, however, is not confirmed by other properties of cork and cuticle.

The cork cells in a branch of Sambucus of one year old, become yellow under the action of nitric acid; a property which is also possessed by the cuticle. This colour is very much deepened by adding subsequently an excess of ammonia. The same takes place with those of Tilia parvifolia, the cork tissues of which are not affected by iodine and sulphuric acid.

When the cork cells are left in contact with strong hydrochloric acid for 48 hours in the air, they assume a violet colour, as we observed in a branch of Clematis vitalba of two years old. This is a positive proof that protein is present in them. (Harting and Mulder.)

The cork from Quercus robur, which was formerly investigated by Chevreul, has been again examined by Doepping (Ann. der Chem. und Pharm., 1843, Maart, p. 286). By treating it with ether, Doepping obtained from it a peculiar kind of wax, which Chevreul had called cerine—which must not, however, be confounded with the substance called cerine by John,—which, on cooling, crystallised in needles, leaving tannic acid and extractive matters in the ethereal solution. Its composition in the hundred parts may be represented by the formula $C^{25}H^{10}O^{3}$. The *suberine* which was left, being purified by digestion with alcohol, ether, water, and diluted hydrochloric acid, had the following composition :—

C	67.80
H	8.70
N	2.30
O	21.20

Doepping does not, however, consider it pure, and in particular thinks it not free of wax. This is the substance of which a large portion is converted into suberic acid ($C^{8}H^{6}O^{3}$), when cork is decomposed by nitric acid, and which imparts a peculiar character, not only to cork, but to all barks containing cork—for like cork itself, the bark of the oak, the

willow, the poplar, the linden tree, &c., on being decomposed by nitric acid, all produce suberic acid.

After the decomposition of cork by nitric acid, there remains cellulose,—according to Doepping, $C^{12}\ H^{10}\ O^{10}$, and not $C^{24}\ H^{21}\ O^{21}$,—and a product of the oxidation of wax and suberic acid.

If we compare this with the analyses of the cuticular substance, mentioned before (p. 473), we perceive a certain connection between the results of the analyses of suberine by Doepping, and those of the cuticle of Agave. Doepping found cellulose, which forms no part of the real cork tissue. But he found, in addition, a substance, which, after allowing for the presence of cellulose, approaches to that which is found in the cuticle of Agave. This analogy, however, is of no value, because when the entire cork is subjected to the action of the mono-hydrate of sulphuric acid, the whole of it is converted into ulmic substances; whereas the cuticle, when treated in the same way, and with a considerable quantity of the acid, produces no ulmin.

We have, however, not found Doepping's analysis of cork confirmed. Pure cork, digested with ether, alcohol, strong acetic acid, and water, left no weighable quantity of ash, and gave the following result, dried at 284°:—

C	65.52
H	7.97

These proportions are entirely different from those found by Doepping. The cork we analysed, however, still contained some nitrogen.

From all we have stated, the following general conclusions may be drawn.

1° The young cells in the vegetable kingdom consist of vesicles, which are composed of pure cellulose, $C^{24}\ H^{21}\ O^{21}$. They do not contain any perceptible particles of solid nitrogenous substances, and therefore the cell-wall cannot be the primary place of chemical action—the primary cause of chemical change of materials; on the contrary, this must take place within the contents of the cell.

2° These cellular membranes either continue, from their first development till their old age, to consist of cellulose alone,—in this case they remain very thin-walled—or they increase in thickness, and take up other substances.

3° These substances are taken up in two different ways, either *within*, or *upon* the thin layer of cellulose.

4° All young parts which do not belong to the cell-wall are originally composed of cellulose; for instance, the spiral threads. As they advance in growth, these take up other matters *within* their substance, and thus become an intimate mixture of cellulose with the substance deposited *in* it, which we have distinguished by the name of intermediate woody matter. The proportion of this deposit increases, and consequently that of the cellulose diminishes. Hence it is that the rings of the annular vessels (those, for instance, in Opuntia), when advanced in growth, contain very little cellulose, and are chiefly composed of intermediate woody matter.

5° The deposition of layers *upon* the cell-wall ought not to be confounded with an incrustation of the wall itself. The two phenomena are entirely distinct from each other.

6° The incrustation of the wall takes place either by means of pectose, or mucilage, or of substances of which the composition is $C^{24} H^{19} O^{19}$, or $C^{24} H^{21} O^{21}$, that is, the same as that of cellulose. The deposition of layers is performed by two substances, the distinctive characteristics of which are now known; and, perhaps, by others besides. With the exception of pectose, the former are produced directly from cellulose, either simply by an isomeric transformation, or by the loss of (the constituents of) water. The latter (those deposited upon the cell-walls), are entirely different from cellulose.

7° The deposition *against* or *upon* the cell-wall takes place either on the inner or on the outer surface of the wall, which consists of cellulose.

8° If the latter contain originally small apertures, as has been often observed, these are, by the subsequent extension of the cell-wall, enlarged. Here, therefore, no deposition of

other substances can take place, and thus points and punctated canals are formed, which are of different kinds.

9° New layers, however, are always deposited on the exterior wall of the layer of cellulose.

10° A certain substance called *exterior matter of woody cells* (p. 451), forms the first layer, which in woody cells is deposited on the cell-wall. In the porous and scalariform vessels the deposit is of the same nature.

11° Between these two layers, that of cellulose and the exterior, a third layer is deposited in the ligneous cells, consisting of what is termed *intermediate woody matter*, in which a transverse section may be distinguished in the form of rings, of which the number is variable.

12° The nearer these layers approach to that of cellulose, the more they pass into it.

13° We have not observed a real incrustation upon the inner surface of the wall; but by this name we indicate the peculiar incrustation of the ligneous cells in Hoya carnosa, which are entirely different from real ligneous cells. Here the layer of cellulose has first been covered, on its outer surface, by a layer of the substance which constitutes the exterior layer of ligneous cells (by the transmission of matters from the contents of the cell). This new layer has now become the basis of a further incrustation, which consists of different layers, presenting a homogeneous mixture of cellulose and intermediate woody matter. In these cells the separate layer of cellulose disappears, which does not take place in real ligneous cells. It is here divided between the new layers of intermediate woody matter.

14° In young and old cells an exceedingly thin membrane has been observed besides, which is contracted by nitric and other acids, and also by alcohol; it is called by Mohl *primordial schlauch*. In thin-walled cells it constitutes a second wall, adhering loosely to the one formed of cellulose; in old ligneous cells it constitutes a fourth wall. In the latter it also adheres but loosely, but even in those which are very old, it is, according to our observations, but seldom wanting. We have called it internal utricle, because it is certain that

it is placed internally, and we do not know whether it is primordial, and much less whether it performs important functions.

15° The thin-walled laticiferous vessels consist of pure cellulose alone; those which are thick-walled, as in the Euphorbias, are surrounded by a thin layer of a substance which seems to be similar to the exterior layer of the ligneous cells.

16° The cuticle of plants is a substance transuded through the walls of the epidermic cells. In some of its properties it is similar to the exterior layer of the ligneous cells of the porous vessels, &c., but in other properties and in composition, it is entirely different from them.

17° Cork cells, of which the chief constituent is suberine, have some of the properties of the cuticle of plants, and of the exterior layer of the ligneous cells, the porous vessels, &c., yet the analogies between them are very limited. Cork cells, the cuticle of plants, and the exterior layer of the ligneous cells are severally to be considered as substances which are chemically different.

18° The great number of small apertures in the young cell-wall is a fact of great importance with respect to our knowledge of the motion of the juices of the cells, because where these apertures exist, these juices may contain particles in a state of suspension.

Finally, we are, in my opinion, sufficiently warranted in assuming the following distinct chemical bodies in the vegetable tissues.

1° *Pure cellulose*, which, by iodine and sulphuric acid, assumes the colour of iodide of starch, and has been already fully described. As far as our present experience goes, this cellulose forms exclusively the wall of the un-incrusted cells and vessels, particularly of the spiral vessels, and has further been indicated as being either the chief or the only constituent of the round and elliptic merenchymatic cells; of the angular and stellular parenchymatic cells; of the wall of the spiral vessels; of the internal wall of annular, reticulated, striated, and punctated vessels; of the internal part of the wall of the

laticiferous vessels; and of the internal wall of the ligneous cells. It constitutes the whole of the young ligneous cells, and thus forms the young cambium, the young medulla, and the cells of the parenchyme, and of the bark, and the fibrous cells of the bark in their young state. It is found in the collenchyme, and forms the cells of the epidermis. Finally, it occurs in incrusted cell-walls, in Hoya, and the seeds of Phytelephas, and Iris.

This cellulose, therefore, if any substance does, deserves the name of a *general* substance. It is the chief basis of the vegetable kingdom.

2° *Cuticular matter*, that which forms the cuticle of plants. It resists the action of the strongest sulphuric acid.

3° *Suberine*, which is found in cork cells. It is converted by sulphuric acid into ulmic substances, and thus differs from the cuticle of plants.

4° *Exterior matter of the ligneous cells*, which appears to be isomeric with the intermediate woody matter; it is also found in the exterior walls of the porous and scalariform vessels. It is, in some of its properties, analogous with the substance of which the cuticle of plants consists; but in properties very important, and in composition, it is entirely different.

We are still ignorant of the composition of this substance, in a separate state, because no means have yet been found for completely isolating it. Its properties, however, differ from those of the substance which it overlies, and which constitutes the real bulk of the full grown wood, viz.:—

5° *Intermediate woody matter*. By this name is meant the substance which constitutes the middle layers of the ligneous cells, the chief part of the rings of the annular cells, of the old spires and of the fibrous cells of the bark. It turns brown by the action of iodine and sulphuric acid, as well as by that of sulphuric acid alone, and is dissolved by strong sulphuric acid. In some elementary parts,—such as old spiral threads, the rings of the annular cells, the scalariform vessels,—it is intimately mixed with cellulose, and in this state it is coloured green by the above reagents, with various tinges. In the incrusting

layer of Hoya carnosa, in the spires of the spiral cells, &c., it exists in the same state. The formula for the ligneous matter of ordinary wood is $C^{40} H^{28} O^{26}$; the composition of that of the harder kinds of wood, of the stone fruits, &c., is expressed by the formula $C^{40} H^{23} O^{18}$, though the latter is probably a mixture of different substances.

6° *Pectose*, as a component part of the cell-wall, intimately intermixed with cellulose, occurs in the epidermic, collenchymatic, and parenchymatic cells of Opuntia brazil: and in the exterior thicker wall of the laticiferous vessels of Euphorbia caput-medusæ.

(An investigation, which I have recently instituted, has shown me that plants contain neither pectate of lime nor pectic acid ready formed. We can, at pleasure, extract from turnips, by an alkali, pectic acid, or by hydrochloric acid, another acid body, soluble in water, which I have called para-pectic acid. For both preparations, however, the application of an elevated temperature is required. From turnips properly washed, cold water extracts nothing, but boiling water extracts para-pectic acid. Pectose is a complex substance. Treated with an alkali at the boiling point, it yields little pectic acid, but a large quantity of certain substances soluble in water, among which is un-crystallisable or fruit sugar. I refer, with regard to this point, to the Scheikundige Onderzoekingen, Deel III., where the details of an extensive investigation of these substances will be found, and which may serve as an amplification of what has been stated before (p. 241) regarding pectic acid and pectin.*)

7° The *substance* constituting the *internal utricle*, which we have not been able more closely to investigate. The same was the case with the *thin exterior wall* of the laticiferous vessels, which, like the internal utricle, is coloured brown by iodine and sulphuric acid.

8° The *substance* of the *horny albumen* of the seeds of Alstrœmeria and Iris, which seems also to be present in the partition-walls of Phytolacca. Its formula is $C^{24} H^{19} O^{19}$.

* See note, p. 389.—*J.*

9° *Two* substances in seeds of Phytelephas, which have both the same composition, = $C^{24} H^{21} O^{21}$: one of them is cellulose.

10° The *pith of the elder tree*, consisting of a substance which must be further looked for in other vegetable tissues Probably it exists also in other kinds of pith.

11° Solid *vegetable albumen*, interwoven through a very large number of elementary parts, such as in the intermediate woody matter, wherever it occurs, either in the ligneous cells themselves, or in the spiral rings, or in any other place. It does not exist, however, in the young *cell-wall*, but is dissolved in the *contents* of young cells.

These are all the substances which we have been able to distinguish with certainty in the elementary parts of plants which we have examined.*

This, however, is certain, that in the vegetable, as well as in the animal kingdom, a very small number of substances is employed to attain the most varied purposes; for investigations embracing a great number of different parts of plants, have yielded to our observation only a very few substances of different chemical characters. This makes it probable that the number of those that belong not to the contents, but to the walls of the cells, is not much greater than we have found it.

I publish this portion of my labours with the lively consciousness that it contains scarcely the first letters of the alphabet; and it is here especially—on this so very little cultivated yet wide field—that I request the indulgence of competent readers.†

* The cellulose of ferment is of a peculiar nature, and ought not to be confounded with ordinary cellulose. By iodine and sulphuric acid it is coloured brown, and only with the aid of the microscope can we discover small intermixtures of a foreign substance which is coloured blue. It is, perhaps, not more than 1-50th part of the whole, and has its origin from the cellulose of the corn. (See further, Scheikund. Onderz. Deel II. p. 409.)

† The highly interesting second edition of Schleiden's Wissensch. Botanik appeared when this investigation of mine was in the hands of the printer. I regret very much that I have thus been prevented from making any use of it.

BB. Animal Tissues.

We have mentioned, in the commencement of this chapter, the various opinions of philosophers in regard to the mode in which tissues are likely to be formed, from which it appears that there is a considerable diversity of opinion on the subject. Whilst some look upon everything as originally consisting of cells, others deny this; and whilst some think that wherever cells exist, they ought always to be regarded as produced from kernels, others on the contrary hold that the kernel or nucleus forms only a part of the contents of the cell, as is the case with a globule of starch or with chlorophyle in plants. It would appear, however, that to account for this difference of opinion, we must look to the class of bodies observed, rather than to observation itself. It is often very difficult to distinguish the kernels in the cells of plants, but they are very rarely absent in the cells of animals, and whilst in plants the cellular form may generally be considered as the primary one, there are many animal tissues which are produced from something else than cells.

The ardent supporters of the cell-theory have, however, stated that even those organs in which cells are wanting from the very commencement, are produced from cells. They call the minute particles which present themselves during the formation of such tissues, kernels, and as they consider these kernels again as utricles with little kernels or nucleoli, it follows that a tissue thus produced has in the end been formed according to the cell-theory. The only difference is, that here the cell is not developed, but its essential part, the nucleus, is present, and this nucleus is converted into a primary fibre instead of into a utricle.

It is manifest, therefore, that the contest here becomes one of terms. When looking at such minute objects as the cell kernels are, it is no longer possible to be certain that they are hollow utricles. They are globular little bodies, the precise characters of which have not yet been clearly made out by observation.

If we, moreover, consider that there are several animal

tissues, which in the beginning of their formation present nothing else but such kernels, and that the transformation of such a kernel takes place without the previous production of a cell, it is evident that the animal tissues do not, by any means, exhibit that general character which is presented by the tissues of plants. There is, on the contrary, among the former, a great diversity in the formation of different tissues from the period of their first development till their growth is completed. In accordance with this, the character of the organs in animals differs considerably from that of the organs of plants; the materials from which they are produced differ very much from each other, and hence arises a series of peculiar stages of development in animal tissues, which cannot be fully explained by the cell theory. Besides, the same animal tissue, when in the act of formation, does not present one mode of development only, but several at the same time,—thus we see a formation of cells with and without kernels, and of other elementary parts without pre-existing cells.

In the animal kingdom no cells are produced without the presence of a substance which is to supply the material for their structure. This substance, therefore, is analogous to the cambium in plants, so called by Mirbel, viz., the cytoblastema. This substance in animals is a transparent liquid, either perfectly clear, or intermixed with minute globules, which are either dissolved before any formation of cells takes place, or during this formation are deposited in the cell-wall and incrust it. When cells or other primary parts are produced from this cytoblastema, it is employed either in whole or in part, and if only a part is used, the remainder assumes different forms, and becomes either a granular solid substance, which is left between the cells, or an apparently homogeneous, solid body, which separates the cells from one another, and serves at the same time to unite them together.

When treating of the cells of plants (p. 398) we remarked that the primary membranes, and the succeeding ones deposited upon them, present a considerable difference in their form and properties, in consequence of which an old cell often consists of substances entirely different from those of a

young cell. The same causes which give rise to this peculiarity in plants, exist also in animals. Here also a cellular membrane is liable to incrustation, but—and this we do not find in plants—it is also capable of being dissolved and replaced by some other substance, or, at least, of assuming such an entirely different chemical character, that we must come to the conclusion that the original cell-wall has undergone an important change. The cause of this difference between the elementary parts of plants and animals is, that there exists in the latter a circulating fluid. In plants the change of materials is limited by the nutritive fluids moving only in one direction; but in animals there exists, throughout their life, in every active part, a renovation of the nutritive fluid, which has a powerful influence upon the character and composition of the parts produced, and through which their primary forms are subjected to much greater changes than those of the organs of plants.

The primary cellular membrane in animal tissues is probably one single substance, or at least, in very different tissues, one single combination of two or more substances which are constantly the same. At present, science can only in part explain what that substance is, or, at least, what forms its chief part. We have seen (p. 303, note, and 316) that the substance which forms the chief constituent of the yolk of egg, is neither albumen, fibrin, nor casein, but a body which can be represented by the formula, $C^{40}\ H^{31}\ N^{5}\ O^{12} + O^{2}$, which, therefore, may be considered as bi-oxide of protein. This substance, from which, by the act of hatching, the first cells are produced, is mixed with a fatty matter. As, however, no such fatty oil is found in any cells that are in the act of development, to whatever tissues they may belong, it may be safely passed over in considering the development of cells in the egg. The material, therefore, from which, by the hatching of the egg, cells are produced, is the bi-oxide of protein. If we, moreover, consider, that in animal tissues the oxides of protein are nowhere wanting,—that in cases of inflammation, the two oxides of protein perspired in large quantity, produce an active cytoblastema from which

pseudo-membranes are rapidly formed,—then we obtain additional grounds for the following conclusion: that, if there does exist in the animal body a universal primary cellular substance, this substance is bi-oxide of protein—a body which is produced from protein by the influence of oxygen, and which cannot be absent from any animal tissue. From what has already been stated regarding the yolk of egg and the inflammatory crust, we learn that this bi-oxide of protein can exist in two states, the one solid and the other liquid.* It may, therefore, by itself as a liquid constitute the whole of the cytoblastema, and by a simple transmutation assume the solid form, in a manner somewhat analogous to the conversion of dextrin into cellulose in plants.

Although, however, bi-oxide of protein may be the material from which, in the yolk of the egg, and in the formation of pseudo-membranes, cells are originally formed, yet one might be inclined to doubt, if this same substance does universally exist in *all* animal cells when in the act of development. We are not entitled to assume its universal presence before it has been proved. I think, however, that the grounds adduced are of sufficient weight to render it very probable, that the cell-wall in the animal body is formed from bi-oxide of protein.

Of the transmutation which this primary animal cellular matter undergoes in the different tissues, we can only speak when treating separately of each tissue. We must here, however, make this general remark, that the conversion of one and the same substance, which constitutes the cell-wall, into the several parts of the organism that are produced from it, among which parts so great differences exist, must have a great influence upon the whole organism; for the diversity, in a chemical point of view, which prevails among various tissues, is great. Although it is true that this chemical diversity is not great among *all* tissues, even though very

* In inflamed blood it exists in a state of solution, or at least closely approaches to that state, and it forms on the surface of the blood a layer of a liquid, which gradually becomes solid, and is then insoluble both in the serum and in water.

different in form, yet such a diversity does exist, and in some tissues, when completely developed, it is so great that we are still entirely in the dark as to their relation to the primary membrane. On the other hand, this diversity in composition, wherever it exists, must necessarily be intimately connected with the change of form that has taken place in the original tissue.

Other means, however, besides a very great difference of matter are made use of by nature for the purpose of producing diversity of form (p. 349). We see that the admixture of extremely minute quantities of other substances causes in the organic kingdom apparently great differences; and were it possible to find in the animal kingdom the most perfect identity in composition, and at the same time difference of form, we should feel inclined to have recourse with the view of explaining it to the same causes, which in inorganic nature throw light upon dimorphism.

It is evident, from what we have here stated, that there exists in the animal organism a continual change of composition as long as the change of form continues. As, in consequence of the rapid re-production that takes places in some tissues, the latter change is going on during the whole life, —the change of materials in the animal body must be much greater than in the body of plants. In the body of a man, duly developed, thousands of cells are daily formed, separated, and excreted,—such as the epithelium cells of the mucous membranes;—thousands of primary fibres decrease and again increase; rest or equilibrium is nowhere to be found; nowhere, therefore, is the form preserved unchanged, and yet the function of no single molecule has been interfered with; though throughout the whole organism no space or atom exists, which does not co-operate to keep up the change of materials which is going on elsewhere.

The whole presents a perfect harmony, in which there is such a close connection between action and reaction, that the human intellect will never be able to trace all the gradations of its working.

But with the increase of the difficulty attending the inves-

tigation of this connection, the duty of the philosopher to exert himself becomes so much the more stringent, and the little that he can comprehend assumes a higher character of beauty.

We know much more of the development of animal tissues than of those of plants, especially as regards their chemical composition. I am, therefore, enabled to treat of this part in a more scientific manner than I could do that of the elementary parts of plants.

The chemical reagents for the elementary animal forms are generally characteristic and peculiar to them; hence, a small number is sufficient to lead to a correct result. We can give no general definition of these reactions, as they differ with the developed elementary parts. In such as are still quite young, and in the act of development, especially in the cellular membranes, the characters of a protein compound are never wanting.

It has, however, been found to be a general property of the nuclei of animal cells, that they are insoluble in acetic, citric, and tartaric acids. Now, as all protein compounds are soluble in acetic acid, this simple reaction shows us that the nucleus is formed of a substance different from that of the primary cell-membrane, as the latter is soluble in acetic acid. This, however, is all we know on the subject. It does deserve attention, nevertheless, that the nucleus is something different from the membrane. If, moreover, the nucleus be the true active part of the cell, that is, its formative part, then it becomes the more important to have a complete knowledge of the nuclear substance;—the more so, because in some tissues the nuclei are converted into fibres.

It is a fact, which seems to be sufficiently confirmed by observation, that the nuclei in some animal tissues produce no cells, but other elementary forms. This fact is not at all to be wondered at. A nucleus is a little group of organic molecules, from which a certain activity, in a chemical sense, proceeds. This little group gives rise to a certain chemical change in the adjoining substances which are held in solution. It makes these substances assume a solid form, and arranges these solid

particles at the surface of the liquid, in a determinate direction; in directions exactly opposite to one another. In this manner Henle's kernel-fibres are produced; but any other fibre differing from nucleo-fibrous matter (elastic tissue), may be formed in this manner, provided there be a difference in the nucleus or in the original little groups of molecules. It is obvious that in case of a difference existing in the latter, the same liquid (cytoblastema or nutritive fluid) must of necessity give existence to a different product. It is not likely, therefore, that all kernels consist of the same substance, because there is such an essential difference in the products which are formed by the agency of nuclei, from the arrangement of particles out of the same nutritive liquid.*

All that is known of nuclei, as productive of fibres, may be, therefore, summed up as follows: that first a little group of solid molecules is separated, and that this little group exercises an influence upon the separation of solid substances from the surrounding liquid. It is proved by observation, that this influence proceeds from two opposite parts of the solid group of molecules.

The production of organic fibres bears, in this respect, some relation to the separation of crystalline substances, by means of molecules of solid substances introduced into a concentrated saline solution.

Further, as regards the development of the elementary animal forms in general, this is a subject of very great difficulty. We have before (p. 354) treated, in general, of the production of cells either from nuclei or in any other way. Our present purpose does not require any further consideration of this subject. The production of fibres, which are of such frequent occurrence in the animal organism, may perhaps be regarded from the point of view just mentioned. As to the development of channels and tubes in the animal body, this undoubtedly takes place in a manner similar to

* It is for new observations to make out in how far tissues, which originally obtain no duly formed cells, should contain, besides nuclei, imperfectly developed cells, which are subsequently converted into fibres.

what appears to take place in plants (p. 420). Finally, the arrangement of these three main elementary forms, cells, fibres, and channels, into compound organs, as far as it has yet been investigated, lies too far beyond the dominion of physiological chemistry, to be fit for a detailed treatment in this place, the more so as I have not been able to clear up this point by observations of my own.

In examining the following animal tissues, it has been my purpose to consider them in relation to the chemical composition of the elementary parts, rather than to give a detailed description of these elementary forms themselves. The former and not the latter was the purpose for which this book was written. For this I have consulted, but not copied, what has been collected on this subject by men skilled in this branch of science, and for further information I refer the reader to Henle,* Valentin,† Krause,‡ Todd and Bowman,§ and others, in whose works a most valuable collection of facts on this subject is recorded.

The close relation, however, which exists between the elementary forms and the chemical composition of the constituents of the organic kingdom, which becomes every day more manifest, rendered it necessary that these animal parts should be submitted to a special microscopical investigation. I have succeeded in obtaining for this purpose the co-operation of my skilful friend, Dr. Donders of the Royal Military Medical School. He has had the kindness to examine the principal tissues in concert with me, and to his acuteness the reader is indebted for whatever useful results the following investigations may have produced.

CC. Horny Tissues.

There is a great number of different parts of the animal organism the elementary structure of which has much similarity

* Allgemeine Anatomie, S. 220. vgg., Leipzig, 1841.

† In Wagner's Handwörterbuch, i. S. 618.

‡ Handbuch der menschlichen Anatomie. Hanover, 1843.

§ The Physiological Anatomy and Physiology of Man. London, 1843.

with that of the persistent horns of the ruminantia; and on this account they have received the name of horny tissues. When young, they all have the appearance of cells with distinct nuclei; but by further development these tissues lose their cellular form in whole or in part, and in most cases present themselves under an entirely different aspect.

This difference, however, is not essential. The cells being compressed, and their liquid contents dried up, plates are generally produced, adhering to one another in different ways. By the application of liquids capable of penetrating the old cell-wall, these plates may in almost all cases be converted into the most beautiful cells.

We are, therefore, already able to give a condensed and characteristic description of the horny tissues. They consist of cells which have undergone no change since the time of their production, except that they have sometimes lost their nuclei, are devoid of liquid contents, and by pressure or elongation form plates or fibres, which, however, may be made to exhibit the shape of cells under the influence of certain chemical reagents.

As to the chemical nature of these tissues, there is much reason to assume that most of them contain one single radical or primary body, a substance of which the cell-wall is wholly or at least chiefly composed. The greater part of the horny tissues are consequently affected by chemical reagents in such a manner that they all exhibit a similar character. Differences, however, do exist, which may result from two causes.

It would appear that all the horny tissues are not formed from the same cytoblastema, for after the formation of nearly the same kind of cellular membranes in different tissues, the remaining constituent of that cytoblastema differs. This remainder is partly disposed between the cells, serving as a ligament or binding material, and partly becomes enclosed within the cell itself.

The greater part of horny tissues, when exposed to the air, are dried up, and hence the cells, however compressed and transformed, contain a dried substance which influences the chemical composition, giving rise to small differences of

which chemistry is not yet able to give a satisfactory explanation.

As regards the ligamentary substance, this also, along with the dried contents, contributes to cause differences in the chemical character of horny tissues, although the several cell-walls in some of them may be completely the same.

It will, however, appear hereafter that the cell-walls of all these tissues do not contain the same substances, although they so far resemble each other, that most of them may safely be comprehended under one class, provided we leave out of account the *simple*, and partly also the *compound, laminated epithelium*.

DD. Epithelium.

The skin, the serous membranes, the mucous membranes, and the internal surface of the blood vessels and serum vessels, are covered with a tissue which is called epithelium, consisting of cells which are well defined, and, in most cases, contain nuclei. The outer skin or epidermis may be obtained in large plates by the action of blistering substances, by the contact of hot bodies, or after death by putrefaction. It putrefies much more slowly than the skin, in which respect it resembles horn and hair, and like the epithelium of the other membranes, contains neither vessels nor nerves. It is produced from substances secreted from the surface of the organs, which it is destined to cover. A liquid is separated from this surface, becomes organised, and forms either one single layer of cells, which seems to be persistent,—such as that upon the serous membranes, in the blood vessels and elsewhere,—or several layers of compressed, dense cells, of which the exterior ones wear off, and are replaced from underneath by others, as in the epidermis (fig. 86). The former constitutes what may be termed *simple* epithelium, the latter, *epithelium in layers*. In the latter the cells sometimes increase in number. If through the influence of external causes the fluid from which the cells are produced is secreted in larger quantities, the layer grows continually thicker, and a callosity is the result.

Or if this cell producing liquid is secreted in large quantity on a small spot, the whole mass solidifies, and by external pressure reacts painfully upon the skin, like a pointed body, and so forces the skin inward (corns).

Both the composition and form of the epithelium are different on different parts that are covered by it. According to Henle, in its cells one or two little nuclei are found, with a dark rim, besides some that are more divided and lighter in colour. The former are insoluble in acetic acid, ammonia, and carbonate of ammonia; but soluble in potash and carbonate of potash. The cells themselves are clear, being filled with a transparent substance, which is either liquid or solid. The cells are, in most cases, placed so near one another that they become polyhedric, like those of plants. In others we perceive a distinct ligamentary substance, which fills up the spaces between the cells, and may be dissolved by a weak potash solution, or by acetic, or sulphuric acid, after which the cells themselves remain behind. Hence, it appears that this inter-cellular matter is different from the cellular matter properly so called. It is most likely derived from what is left of the cytoblastema after the cell formation. In many solvents, especially potash and sulphuric acid, it is more readily soluble than the cell-wall itself, and thus these liquids afford a means of isolating the cells.

The mucous membrane of the mouth, the nose, and other parts, gives us a ready opportunity of studying young cells of epithelium. What can be scraped off the surface of these parts is young epithelium. I know no way more apt and easy of obtaining a very correct view of new cells with their nuclei, than to scrape off a little of the integuments of these parts and to place it under the microscope. The mucus of the mouth and nose always contains an admixture of recently excreted epithelium cells (see p. 240), and these integuments are therefore to be considered as constant sources of new cells which are expelled in the form of excretions, of which the quantity may increase considerably in illness, and which, when separated in large quantities, either afford a means of diagnosis as to the nature of the disease (fur, upon the tongue), or

when separated, exercise an influence upon the organism, which again may be a beneficial one (critical evacuations of the primæ viæ), or the contrary (mucous flow).*

Epithelium may be either *laminated*, or *cylindric*, or oscillatory. The first is spread over the surface of the serous membranes (fig. 87), which cover the cavities in which the intestines are loosely hung up, and also the exterior surface of these intestines themselves, as for instance, the peritonæum. When, therefore, a serous membrane is analysed, we have to expect not only the substance which by boiling is converted into glue, but also the constituents of this laminated epethelium, which, therefore, must first be scraped off with a knife (see p. 350). Very much the same form is characteristic of the integument of some other mucous membranes, for instance, of that of the mouth (fig. 89), and that which covers the inside of the heart, the arteries and veins, till these pass into the capillary system. It is not soluble even in boiling water, nor in ether, alcohol, ammonia, carbonate of ammonia, or dilute mineral acids; it is soluble, although not easily, in acetic acid, but very easily in caustic potash.

Laminar epithelium. To this belong two kinds: that consisting of one layer, and that which is formed of several layers.

We have examined the *simple epithelium* of the serous membranes, especially that of the peritonæum.† It also exists on the inside of the arteries, where we found it to be al-

* These cells of epithelium are, therefore, in very large quantities, mixed up with the excretions, of which they form a constituent which should not be overlooked. They contain nitrogen, and the use, therefore, of these excrements as a manure, is derived partly from their presence, partly from the admixed globules of mucus from the primæ viæ.

† *Single laminar epithelium*, obtained by scraping off the internal surface of the peritonæum of a cow, consists of very thin polygonal plates, which lie in close mutual contact, and have granular contents. A nucleus is found only in a few of them (fig. 87). By the action of weak acetic acid they become much paler, but at the same time more granular. No more nuclei appear, and the cells seem to be free of them. The granular matter extends itself to the edges. By the action of stronger acetic acid they are detached from one another, and remain lying at some distance. They have now become globular, remain granular, and of the same size as at first (fig. 88). Those scraped off the aorta of a man are of the same structure, but still paler and less

most identical with the former. It consists of very flat small cells with granular contents. We have, however, not been able to find out how the wall, the contents, or the nuclei, if present, are constituted, as it is impossible to collect a quantity of these large enough for examination.

We have, however, no sufficient reason for classing this epithelium as to its chemical nature with the following kinds:—

The *compound* or *stratified epithelium* is of various characters. To this belongs, in the first place, that which covers the cavity of the mouth. It may easily be removed from the internal surface of the cheek, and thus, although mixed with a little saliva and mucous globules, serves well for examination. We have, however, as yet only a limited knowledge of the nature of its cells, as only a small quantity of them can be obtained.

They present themselves as large, angular plates, containing a nucleus or kernel, and partly covered with a granular substance (fig. 89). These plates, by immersion in potash, are expanded into perfect cells (fig 90, *a*, *b*, *c*): the alkaline liquid does not at first dissolve the walls, but by an endosmotical action penetrates through them and converts the plates into ellipsoids (fig. 90, *d*).*

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distinct. They have, however, a very distinct, large nucleus, surrounded by a clear rim.

Those obtained in the same manner from the surface of the cerebral ventricles of a cow are again similar to the former, but lie at a certain distance from one another, are very pale and thin, circular, and contain nuclei. Acetic acid makes them still paler, and the nuclei cease to appear; the contents, however, appear granular. We could not discover any oscillatory hairs upon them. (Donders and Mulder.)

* *Epithelium from the cavity of the mouth.* This consists of transparent, angular, irregular plates, with large nuclei, and a great number of small granules diffused around the nucleus (fig. 89). The latter become pale when acted upon by acetic acid, which is very remarkable, as they generally are rendered much more distinct by this acid. The nuclei present no trace of any peculiar substance. After the application of acetic acid, the granules in the remaining part of the plates have much increased in number, the whole of its surface being nearly covered with them. On the subsequent addition of water no change is produced either in the cells or in the nuclei.

Strong nitric acid renders them pale, and makes the nuclei disappear; on ammonia being then added, they again become more distinct, and the contents

Judging from the knowledge which we possess of them at present, the walls and nuclei of these cells differ from those of all the other horny tissues. They contain only a minute quantity of protein, which is a main constituent of all real horny tissues.

The Epidermis. All that we know, chemically speaking, of the epithelium, with which the several parts of the body are covered, is confined chiefly to the epidermis. We find in it first the almost invariably present so-styled inorganic salts, a little fat, and the constituents of sweat, with which the epidermis is saturated—such as lactate of ammonia, lactic acid, acetic acid, common salt, phosphate of soda, phosphate of lime, oxide of iron, and chloride of ammonium (Thénard, Berzelius, Anselmino),—and further, five per cent. of a substance producing glue, which can be dissolved out by boiling in water. This substance, however, is probably not a consti-

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of some become more granular, but the nuclei are not restored. They do not turn yellow, but have assumed a regular elliptic form. The cell-walls become faint yellowish, when heated with nitric acid and then supersaturated with ammonia. The cells have become spheroidal.

They are not readily dissolved in a strong, that is, a saturated solution of potash; on the subsequent addition of water they swell, and their laminar form is changed into an elliptic and globular one. Both the nuclei and the granular bodies disappear; nothing remains but a very transparent utricle of a globular form, which is at last dissolved (fig. 90, *a*, *b*, *c*).

After having been left in the strong potash solution for six hours, their form has become nearly globular, the cells now present an inclosed granular substance, and in every cell a nucleus is found. When water is added, they revolve and float in the liquid as globular cells (fig. 90, *d*); they become much paler and are slowly dissolved. The nuclei disappear sooner, and are first reduced to a granular substance (fig. 90, *b*, *c*); the granular contents of the cells become soon invisible in the diluted potash ley (fig. 90, *d*).

A cell which revolves and appears as an ellipsoid, shows its nucleus at the same time as a little globular body, for in every position its diameter is the same.

By the action of tincture of iodine the cells become intensely brown, and the nuclei become much more distinct.

Sulphate of peroxide of iron does not change their colour. These cells are, therefore, not the cause of the red colour which saliva assumes by the action of a salt of iron.

On a later examination of the epithelium of the peritonæum of a cow, we found in every cell a distinct nucleus of a comparatively large size (fig. 87, *b*). (Donders and Mulder.)

tuent of the tissue itself, which contains 93–95 per cent. of insoluble matter.

The epidermis is readily soluble in strong sulphuric acid and in strong alkalies, and thus is explained why this acid and the alkalies are unctuous to the touch. When digested in alkalies, however, even for many days, a small residuum is left undissolved. The alkaline solution, when mixed with acetic acid, gives a white precipitate. By nitric acid the epidermis becomes yellow, and is converted into xantho-proteic acid. Nitrate of silver colours it violet, first from the presence of common salt, by which chloride of silver is formed, which changes in colour by exposure to light, then because the sulphur from the epidermis gives rise to the production of black sulphuret of silver, and also because the oxide of silver is reduced to the metallic state (by the lactates), whilst the nitric acid combines into xantho-proteic acid. When held in the flame of a lamp it burns with the smell of burning protein. It is not dissolved by alcohol and ether. By the action of nitrate of mercury it becomes reddish brown.*

* *The epidermis of the breast of an almost full grown fœtus.* The transverse section is left in a strong potash solution for six hours. On the addition of water, the epidermis gives way; well defined cells swell out on the inferior surface, and the whole presents a cellular appearance. The cells become gradually more visible, and the entire epidermis appears as a mass of superimposed layers of regular cells, of an elliptic form.

The epidermis, therefore, consists of a number of layers of flattened cells, which are fixed upon and to one another, and become expanded by the influence of potash and water.

After the epidermis has given way, a finely granular substance is seen floating between the skin and the epidermis. This is probably the cytoblastema of the epidermis mixed with nuclei.

A piece taken from the palm of the hand of the fœtus, parallel to the surface, after having been left in a strong solution of potash for seven hours, presents nothing but complete elliptic cells, with distinct little nuclei. A few become isolated and float in the liquid. The addition of water produces no change.

The epidermis from the palm of the hand of a full grown man, taken parallel to the surface, after having been left in strong potash for seven hours, presents also nothing but elliptic cells (fig. 91), and when the distance of the focus is changed and water added, a considerable difference in the distance between two opposite cells is to be seen.

The plates are, therefore, swollen into cells, which are very transparent. Sulphuric acid makes them contract, and they become much less transparent, although their cellular form is still very recognisable. In potash the cells be-

The composition of the epidermis, of which the soft, interior part has been erroneously considered as a peculiar integument (rete Malpighi mucosum), is not to be derived from that of hair; for the similarity of composition between all the horny tissues, found by Scheerer, has not been confirmed by more recent investigations.

It is true that the differences found by elementary analysis are not great, but the properties of the epidermis differ essentially from those of hair, and hence they are not to be considered as belonging to the same class of tissues.* Hair

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come isolated, float away, and present no nuclei; the plates even of the upper layers are converted into true cells (*a*). The cells of the under layers are smaller (*b*), those of callus or thickened skin more globular (*c*).

The epidermis of the thigh of a full-grown man, after having been in weak acetic acid for four hours, has become more transparent (fig. 86). The exterior layers are little plates (fig. 86 *a* presents a transverse section, fig. 92 the surface); below these there are little cells with nuclei, regularly arranged (fig. 86, *b*), below these again, there are nuclei irregularly situated (*c*), and then a layer, in which nothing can be distinguished (*d*). After this comes the real skin (*e*).

When the epidermis has been kept in a large quantity of sulphuric acid for six months, it is apparently dissolved, but when placed under the microscope, many plates are still visible, in which the structure of the epidermis remains recognisable. On the addition of water they appear as regular cells.

When kept for six months in strong nitric acid, the whole of the epidermis is converted into xantho-proteic acid, but it still exhibits the same laminar structure, the plates being, however, separated from one another, and with dark edges. Many among them, when revolving, appear to be elliptic, others are angular; in no case, however, are they flattened, but are either parallellopipeds or cubes. In several, a large air-bubble is enclosed (of deutoxide of nitrogen), —an additional proof that the little bodies have actually swollen in all their dimensions.

When kept in strong acetic acid for six months, the epidermis is left unchanged, being only rendered more transparent.

When kept in hydrochloric acid for the same period, it is converted into ulmic acid, but in a part of it the form is still quite distinct.

When kept in strong potash-ley for the same time, it is completely dissolved; only a few particles, of an irregular appearance, are left behind.

* Scheerer has analysed the epidermis of the soles of the feet, and found for its composition (Annalen der Chemie und Pharm. Bd. 40, S. 55)—

C	50.75
H	6.76
N	17.23
O, S	25.26

seems, on the contrary, to approach in character to horn and whalebone, although it differs essentially from these in other respects. On the other hand, the properties of the nails are so similar to those of the epidermis, that we should be inclined to consider them as bodies of the same class in a chemical point of view, if their composition were not different; for the epidermis contains a much smaller proportion of sulphur than the nails, and there is also a difference of one per cent. between the proportion of carbon in the epidermis and that in the nails; consequently they are not identical.

The composition of the epidermis may be expressed by the formula $5\,(C^{40}\,H^{33}\,N^{6}\,O^{15})\,S$,* but it is impossible, as yet, to demonstrate the absolute correctness of this formula. On the contrary, I question the purity of the epidermis as a chemical body. As to the value to be attached to the examination of it, I consider it much less than in the case of hair, the nails, horn, whalebone, &c., because the contents of the flattened cells in the epidermis appear to be much greater than in any of the other horny tissues just mentioned, of which the small contents admit of being neglected, and the knowledge of which, in a chemical point of view, is confined to that of the cell-wall, of which almost the whole tissue consists.

It is certain, however, that the epidermis is similar in composition to no other horny tissue with which we are yet acquainted, and that it is characterised by containing a much smaller proportion of sulphur.

When any of these bodies is dissolved in a weak potash

On repeating these analyses of the epidermis of the soles of the feet, previously treated with ether and alcohol, I have found (Scheikundige Onderzoekingen, Deel III.)—

C	50.28	49.84
H	6.76	6.75
N	17.21	
O	25.01	
S	0.74	

The quantity of hydrogen and nitrogen found by Scheerer has, therefore, been confirmed, but that of carbon is too large.

* $5\,(C^{40}\,H^{31}\,N^{5}\,O^{15} + N\,H^{3}) + S$. See *Horn*.

ley, and acetic acid added drop by drop, in a quantity not sufficient to render the solution acid, a precipitate of protein is formed, which is but small when hair is used, and smaller still from whalebone, horn, and epidermis: but when the liquid is very much supersaturated with the acid, an abundant precipitate is produced in the solution of the three latter bodies. This precipitate is bi-oxide of protein.

There is another property in respect of which the epidermis resembles horn and whalebone, but in which they all three differ from hair, viz., that they become first gelatinous and are subsequently dissolved in strong boiling acetic acid, in which hair is almost insoluble. From the solution of all three in acetic acid, ammonia throws down bi-oxide of protein, which shows that they all contain this substance ready formed.

One of the difficulties attending our attempts to learn the elementary composition of the epidermis is, that it is impregnated with several foreign substances, and contains only 93 to 95 per cent of real horny matter, according to John. Some of these substances may be removed by digestion with ether and alcohol, but the application of water causes the disengagement of sulphuretted hydrogen, and thus prevents a correct determination of the sulphur. We have, therefore, when making the analyses just mentioned, abstained from treating the substance with water.

The epidermis is not, however, entirely similar to horn and whalebone, as will be shown presently.

It is sufficiently known that the epidermis wears away, and is constantly renewed from below. This renovation is effected in the same way in which cells in general are multiplied (p. 355) from below, and on the spot where the cell-producing viscous fluid is secreted by the skin (fig. 86, *d*). Hence the undermost cells are softer, and were considered by Malpighi as a peculiar integument (fig. 86, *b*, *c*). By this renovation of the cells from below, and the wearing away of the superior cells, the inferior ones become at last the superior and exterior cells, and with the epidermis this process continues in the same way as it takes place in the stratified epithelium of the mucous membranes. The substance,

therefore, of which the epithelium consists, is continually secreted from the body; a substance which is secreted as a fluid, becomes organised into cells, wears away, is replaced by a new quantity, &c. Thus a considerable quantity of protein is expended by the organism to perform a seemingly trifling service.

It often happens that a large quantity of these cells is separated and replaced by new ones. In measles and scarlet fever, for instance, we see entire layers falling off. After a wound, the epidermis may be seen in the act of forming on the new tissue.

The so-called horny tissues, when wholly developed, present always a compressed cellular form, and hence as regards the history of their formation they may be included under one class. The following, however, are exceptions, of which we only make mention here in passing, in consequence of the defective knowledge we possess of their chemical character.

First, the cylindric epithelium (fig. 93), which owes its origin to cells that have originally been globular, but which were afterwards extended only in one direction so as to become little cylinders. In the human body, however, they are in most cases of a conical shape (*a*), and are either compressed upon one another when their sections are polygons, or they leave interstices between them, which are filled up with a transparent intercellular matter (*b*).

The substances of which these cells consist, have the same chemical reaction as those of the former. They are diffused over a large portion of the intestinal canal from the cardia to near the anus, and in the biliary ducts, and they serve as an integument to several other organs.

Nothing is known of their origin, in a chemical point of view. It does not probably, however, differ much from that of the laminated epithelium, for this is acted upon in a similar manner by reagents.

Second, the epithelium with oscillating hairs (fig. 94) of which the structure is not essentially different from that of the cylindric epithelium, except that its free surface is studded with groups or parcels of minute hairs (*a*), which are in continual

motion during life. This integument is found in the respiratory organs, in the female sexual organs from the half of the mouth of the uterus upwards, and in the ventricles of the human brain. We know nothing yet of its chemical nature.

A great number of minute animals, especially of infusoria, exhibit on their surface various flickering or oscillating motions. They may also frequently be seen in young animals. Regarding the cause of this motion, we are yet quite in the dark, for it is sometimes seen to continue even after the death of the individual, and the rapidity with which it is performed is surprising. The chemical character of this epithelium is equally unknown.

The *nails* are not essentially different from the epidermis, either in origin, in structure, in nature, or in composition. They are only harder, and less elastic. Like the epidermis, they consist of series of cells grouped together, but in greater number. It is known that they are in a continual state of renovation. Like the epidermis, nails of any kind are restored from underneath by the formation of new cells from new cytoblastema. They are restored from all places where they are connected with the epidermis underneath, that is to say, from the under surface and on the posterior and lateral edges, which are enclosed in a folding of the skin; it takes place chiefly, however, on the posterior edge, where the matrix properly exists. Matter is there secreted, which is converted into cells, and from which the plates of the nails are formed, which appear from without the skin, in the shape of an agglomeration of densely packed cells, exactly similar to those of the epidermis. Like the epidermis, therefore, they may be considered as organised secretions through which one of the most necessary constituents of the body, its protein, is discharged, and consequently diminished in quantity.*

* *A section of a full-grown nail of the fingers*, parallel to the surface, presents bands running irregularly; when cut transversely at the hard foremost part of the nail, it presents lines running like bands mixed up with small dark bodies (cavities').

When a small portion is scraped off its surface and left in strong acetic

The composition of the nails differs from that of the epidermis. Human nails have been analysed by Scheerer; those of cows and horses are not essentially different, although their composition is not quite the same, because the dried contents are of a different kind. The cell-wall itself, however, seems to be the same in all.* Lauth thinks that they

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acid for three hours, it presents horny plates of a greater transparency, some of which contain a kernel (fig. 95, *a*).

When cut through transversely and left in a strong solution of potash for six hours, it has become granular, and a distinct form can no longer be distinguished. When water is now added, a net of meshes appears, each of which has a distinct kernel. These meshes, formed from the outlines of flattened cells, become more globular after the water has acted upon them for some time. Some of them even become completely globular (fig. 95, *b*). In each of them a kernel is distinctly visible (*b*, I). When the water is poured off, a granular substance escapes along with it, and the cells become more distinct and expanded. They are here also attached to one another. On acetic acid being added, the whole is contracted, becomes darker in colour, and the contents of the cells become granular.

After being left for six hours in a solution of four parts of potash in one of water, no more water having been added, the cells are distinctly visible and much swollen.

A section taken parallel to the surface and kept in a strong solution of potash for six hours presents curved lines. On water being added, the whole swells much, and the cells of the surface become distinctly visible. A longitudinal section exhibits the same reaction.

A section of the nail of an almost full-grown fœtus, taken parallel to the surface, when kept in a strong solution of potash for six hours, no more water being added, presents isolated cells, each of which contains a kernel. The cells have an ovate form, and become paler on the addition of water.

The whole tissue, therefore, consists of nothing but cells. These cells contain kernels, and probably also an inclosed substance. When in the natural condition, the cells are flattened, forming plates, which lie parallel to the plate or surface of the nail itself. (Donders and Mulder.)

* Scheerer has found human nails to be composed of (Annal. der Pharm. *l l*),—

C	51.089
H	6.824
N	16.901
O S	25.186

The following result, which I obtained from human nails (Scheikundige Onderzoekingen, Deel III.) agrees almost exactly with that of Scheerer,—

C	51.00
H	6.94
N	17.51
O	21.75
S	2.80

contain more phosphate of lime than the epidermis. Human nails, however, which contain more inorganic substances than any other kind, contain about one per cent., and human epidermis leaves the same quantity of incombustible residue. Hence we may consider the alleged difference to have no existence. As to the difference in the amount of carbon obtained by the analysis of different kinds of nails, this is also attributable to a difference in the contents of the cells, or to a smaller or greater proportion of the substance by which the cells are united together.

If we take for the composition of nails that obtained by the analysis of cow and horse-hoofs, as we have not been able sufficiently to repeat the determination of sulphur in human nails, we find it represented by the formula C^{120} H^{93} N^{17} O^{36} S^{4}.*

This formula, which we shall explain when treating of horn and hair, is equivalent to $[C^{40} H^{31} N^{5} (O^{12} N^{2}) + 2 (C^{40} H^{31} N^{5} O^{12} S^{2})]$.

It expresses an intimate combination of two substances, which may be considered as bi-oxide of protein, but in which the additional quantity of oxygen by which this bi-oxide differs from protein itself, is replaced by N^{2} and S^{2}. The nails of cows and horses, when dissolved in potash-ley and precipitated by acetic acid, yield bi-oxide of protein, but no protein. (See *Horn*, *Hair*, and *Whalebone*.)

From horse-hoofs extracted with alcohol and ether I obtained		From cow-hoofs treated in the same way (Scheik. Onderz. Deel III.).	
C	51.41	C	51.10
H	6.96	H	6.77
N	17.46	N	17.28
O	19.94	O	20.25
S	4.23	S	4.60

	Atoms.	Calculated.
* C	120	51.64
H	93	6.54
N	17	16.95
O	36	20.34
S	4	4.53

EE. Horn.

Perennial horns, such as those of the cow, &c., are in many respects similar to epidermis and nails, while, on the other hand, they differ from hair both in structure and in their chief constituents. They consist of numberless bundles of fine threads, lying side by side, as is the case in the principal portion of hair (p. 520). When subjected to the action of a solution of potash in water, these bundles unfold into little plates, which gradually expand into regular cells, each one of which contains a distinct kernel (fig. 97, *b*). After the addition of sulphuric acid, the form of the cells becomes more defined, being either ovate or globular. The horny tissue, therefore, is different from that of hair, as in the latter, excepting in the pith or medulla, cells are no longer visible.* As regards its origin, however, it resembles hair, it being also

* *White cow-horn.*—A longitudinal section taken vertically to the surface, after being soaked in a strong solution of potash for five hours, presents fibres densely crowded and running irregularly. After the addition of water, these fibres become large, more elongated and distinct, and the whole is rendered much more transparent. When more water is added, the fibres become looser and more like the outlines of cells, in each of which a small kernel may be distinctly seen (fig. 96).

A transverse section, after having been kept in potash for five hours, also presents a shapeless appearance, having the same seeming fibres densely bound together, which, however, in some places resemble the outlines of cells. On water being added, the cellular structure is more and more developed, the outlines become detached from each other, and each cell is seen to contain a very distinct kernel. The cells themselves are very transparent. When the potash is saturated with dilute sulphuric acid, the cells become much more visible, and assume an almost globular or ovate form, without any contents, the kernels having been rendered invisible.

The texture of cow-horn, therefore, is entirely homogeneous, consisting wholly of cells, without any visible contents, and which, while in the tissue, are flattened, but swell under the action of potash. A granular substance is to be seen on the surface of the liquid.

A section, taken parallel to the surface and kept in a solution of potash for five hours, exhibits nothing very distinct. On water being added, it becomes similar in appearance to that of the first-mentioned longitudinal section. The subsequent addition of dilute sulphuric acid renders the cellular structure less distinct. If the action of sulphuric acid is continued longer, the whole becomes too much contracted, and nothing can be properly distinguished.

A transverse section, having been kept in potash for 22 hours, without the

formed from a substance secreted by a little cavity of the skin, and of which the chief constituents must be the same as those from which the epidermis and nails are built up.

The colour of horn varies, but this variation, like that of hair, is probably not caused by any essential difference.

Horn, when grated, gives off a peculiar smell. When powdered and heated a little above 212° F. it becomes soft, and in this way separate portions may be united together. In respect of this property it differs from hair.

When boiled in water, horn becomes soft, but no glue is formed. When treated with alcohol and ether, nearly the same substances are extracted as from hair. When treated with water at a moderate heat, it gives off a certain quantity of sulphuretted hydrogen; this gas is produced even when powdered horn is in contact with water at the ordinary temperature. This disengagement of sulphuretted hydrogen is probably due to a cause similar to that by which the same gas is produced from coagulating eggs. Sulphuret of sodium is formed from the sulphuro-phosphuret of protein and the carbonate of soda contained in the white of the egg, and this sulphuret of sodium, when in contact with the carbonic acid of the air, gives rise to the disengagement of sulphuretted hydrogen. When horn is grated and exposed to the air, a small quantity of the same gas is always liberated, owing to the alkaline liquid with which horn is saturated.

When kept in strong sulphuric acid for some time, horn is completely dissolved. By nitric acid it is converted into xantho-proteic acid. It is not dissolved by acetic acid at the

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addition of water, presents exceedingly well-defined cells, most of which contain a distinct kernel (fig. 97). The addition of water renders them much more transparent, but by sulphuric acid they again become very visible.

A section parallel to the surface, kept in strong sulphuric acid for six hours, presents the appearance of little fragments, consisting of bent lines, which have been removed from the surface. They float about like irregular little plates. A section perpendicular to the surface, where the whole is coherent, produces larger laminæ.

In a section parallel to the surface, kept in sulphuric acid for 24 hours, the laminæ give way and float through the liquid as little, bent laminæ (fig. 98). (Donders and Mulder.)

ordinary temperature. By hydrochloric acid it is, after some time, converted into humate of ammonia.

Horn, when left for some time in a weak potash-ley, is almost completely dissolved; only a few shapeless particles being left behind. The solution has a light yellowish colour. On the addition of a little acetic acid, a minute precipitate is formed. If this precipitate is separated by filtration, and an excess of acetic acid added to the remaining solution, a fresh quantity of another precipitate is obtained. The former is protein, but the quantity produced is so trifling that it is to be considered as one of the accessory, and not of the essential constituents of horn. The composition of the latter precipitate is the same as that of bi-oxide of protein, according to analyses made by J. L. Tilanus.*

When horn is boiled in strong acetic acid, it first becomes gelatinous, and is at last dissolved. Ammonia added to this solution produces a precipitate of which the composition, according to J. L. Tilanus, is about the same as that of tri-oxide of protein.†

When chlorine is passed through horn, suspended in water, a compound is produced of chlorine and horn, which, accord-

* Scheikundige Onderzoekingen, Deel III.

C	52.90	53.15
H	6.72	6.67
N	15.97	15.97
O	24.41	24.21

	Precipitate from acetic acid.			From another preparation.	Atoms.	Calculated.
† C	50.90	51.36	51.25	51.01	40	51.45
H	6.49	6.59	6.46	6.59	32	6.72
N	15.66	15.66	15.53		5	14.90
O	26.32				16	26.93
S	0.63					

Compare the anhydrous tri-oxide of protein from hair. This tri-oxide of protein from horn is not insoluble in water.

Cow-horn analysed in its natural state, was found by J. L. Tilanus to consist of:—

C	50.94	50.86	50.80
H	6.45	6.83	6.77
N	16.30	16.30	16.30

ing to the analysis of J. L. Tilanus,* may be represented by the formula

$$C^{40}\,H^{31}\,N^{4}\,O^{17} + Cl\,O^{3}.$$

A similar compound has also been obtained from whalebone, and as the composition of the latter substance approaches that of horn, it at first appears that we are entitled to consider whalebone and horn as tissues of the same kind.

This conclusion, however, is incorrect, because, first, when whalebone is dissolved in potash-ley, and acetic acid added, no precipitate is formed, whereas an abundant one is obtained from horn; secondly, when whalebone is dissolved in strong acetic acid and ammonia added, a precipitate appears, which is bi-oxide of protein, whilst that from horn

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Scheerer obtained from buffalo-horn (Ann. der Pharm. Bd. 40, S. 56),—

C	51.99	51.16
H	6.72	6.60
N	17.28	17.28
O S	24.01	24.96

This difference in the results obtained from horn respectively by Scheerer and Tilanus, rendered it necessary that the experiments should be repeated. Other specimens of cow-horn, however, gave the same result:—

			Atoms.	Calculated.
C	51.08		80	51.2
H	6.80	6.84	64	6.5
N	16.24	16.00	11	16.0
O	22.51		28	22.1
S	3.42	3.33	2	3.2

* Chlorite of horn.

C	46.70	47.06	47.18
H	5.86	5.77	6.04

On repeating these analyses with the compound, obtained from other cow-horns, the substances dried at 212° F. yielded (Scheikundige Onderzoekingen, Deel III.):—

	Found.		Atoms.	Calculated.
C	46.97		40	46.34
H	5.99		31	5.87
N			4	10.75
O			20	30.33
Cl	5.50	5.81	1	6.71

differs entirely from the former both in composition and in properties, and is almost identical with horn itself; thirdly, the compound of horn and chlorine just mentioned, cannot be obtained from whalebone by simply subjecting it to the action of chlorine, but only after it has first been dissolved in potash.

The composition of horn is also different from that of whalebone, and at the same time from that of the epidermis and nails. The determination of the nitrogen in horn, as made by Scheerer, is incorrect.

If we bear in mind that potash extracts from horn a large quantity of bi-oxide of protein, it becomes probable that its formula is

$$C^{80}\,H^{64}\,N^{11}\,O^{28}\,S^2 = 2\,(C^{40}\,H^{31}\,N^5\,O^{14}\,S) + N\,H^2,$$

that is, a mixture of bi-oxide of protein with sulphur and amide. If this is the case, the substance precipitated from acetic acid may contain the constituents of one atom of ammonia ($N\,H^3$) less, and two atoms of oxygen (O^2) may be substituted for two atoms of sulphur (S^2), in this manner:—

$$C^{80}\,H^{62}\,N^{10}\,O^{28}\,S^2 = 2\,(C^{40}\,H^{31}\,N^5\,O^{15}).$$

The composition of this precipitate was:—

	Found.		Tri-oxide of protein. Atoms.	Calculated.
C	50.90	51.25	40	51.45
H	6.49	6.46	32	6.72
N	15.66	15.53	5	14.90
O	26.32		16	26.93
S	0.63			

The calculated numbers agree tolerably well with those derived from analysis, if we make allowance for the portion of sulphur which exists in the precipitate from horn, and which is attributable to an imperfect decomposition.

In endeavouring to explain this composition, we must bear in mind the following considerations.

We know that it is one of the properties of bi-oxide of protein to be converted into the tri-oxide. When, for in-

stance, fibrin is boiled in water, the bi-oxide is produced first; and by protracted boiling this is changed into the tri-oxide. The latter substance we have already met with under two forms, viz., as a hydrate soluble in water, and in an anhydrous state, insoluble in water. (See *Hair.*) When, therefore, amide is changed into ammonia, and the oxygen of the water combined with the organic substance, and at the same time oxygen taken from the air, and thereby the sulphur liberated,—then the precipitate produced by ammonia in the acetic acid solution, must of necessity have a composition approaching either to that of bi- or of tri-oxide of protein. The latter appears to be actually the case; for in this way horn produces a substance, which may be represented by the formula $C^{40}H^{32}N^5O^{16}$.

I think that the facts above stated are in favour of the assumption, that horn is composed according to the formula $2(C^{40}H^{31}N^5O^{14}S) + NH^2$, which is the same as that for the cell-wall. The small differences existing between the calculated numbers and those found by actual experiment, are to be accounted for by the contents of the cells, and the intercellular matter. It appeared, however, from microscopic observations, that these differences cannot here be material.

FF. Whalebone.

Although we are unacquainted with the manner in which this gigantic product of the whale is originated, we are, however, sufficiently warranted in viewing it as a product similar to nails, hair, and horn. In the upper jaw of the Balæna mysticetus and other species, a set of plates is found, which are inserted at right angles into the circumference of the jaw, and have a considerable size. By means of these plates the mouth is closed in such a manner that the water can pass through, but the small fishes, which along with the water have been taken into the mouth, are kept back.

Whalebone has been analysed by van Kerckhoff* Its composition is very simple. The whole tissue consists of

* Scheikundige Onderzoekingen, Deel II., p. 347.

cells flattened into little plates, which are joined together in two different directions. In large specimens of whalebone little medullary canals run in the longitudinal direction; these canals are placed in groups, and each of them is surrounded by a set of concentric sheaths (fig. 102; compare fig. 103, 104, and 105). Of these the black part of the whalebone consists. A group of these, again, (fig. 99, *b*) is inclosed in the main part of the whalebone, which is of a grey colour (*a*). The latter consists also of plates (fig. 100 and 101), like the black portion, but these are placed parallel to the surface. When left in potash ley for a long time, the whole tissue is converted into a collection of cells, which are regularly formed (fig. 106). In whalebone these cells are compressed and joined together in the shape of plates, which are seen in the black part, and constitute the sheath round the medullary canals. The observed constituents of whalebone are: cells, their dried contents, the connecting material between them, a little fat, and a black granular substance in the medullary canals.*

* Whalebone consists of two different portions. The one has a homogeneous, greyish appearance, and may be called the grey substance (fig. 99, *a*), the other is darker in colour, and may be best designated by the name of the black substance (fig. 99, *b*). A thin, longitudinal section of the latter presents, under the simple microscope, distinct dark lines, running parallel to one another, between which the tissue has a colour more inclining to grey. It may, therefore, also be called, striated substance.

The piece we used for examination was about two millimetres thick, and consisted of a central black plate of one-half millimetre thick, contained between two grey plates, each of a thickness of about three-fourths of a millimetre. These three plates may, therefore, be distinguished both on a longitudinal and on a transverse section. (Fig. 99.)

A thin piece of the *grey part*, cut through transversely, presents under the microscope a great number of parallel, more or less interrupted lines, which indicate a laminar structure (fig. 100). This shows that the grey substance consists of very thin plates, which cover one another parallel to the surface. Between these plates very small elliptic, dark spots may be seen, at regular distances from each other. When the focus is lengthened a little, these spots soon lose their dark appearance, and hence they seem to be simply little cavities (*a*).

On the addition of thick Venice turpentine, these spots become at first still darker. By thin turpentine they are immediately rendered very transparent, which makes it probable that they are in reality little cavities.

A longitudinal section along the edge, which had a thickness of two milli-

The substances extracted from whalebone by ether and alcohol, are: stearine, elaine, phocenine, a very small quantity of two different extractive matters, common salt, and sulphate of potash. 100 parts of whalebone contain of substances

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metres, presented the same appearance. The cavities now appeared narrower and more elongated (fig. 101).

In a longitudinal section, parallel to the surface, the laminar structure can only be recognised from the plates being occasionally cut through. When this section has been taken completely parallel to the surface, the laminar structure cannot be discovered. The plates, therefore, run parallel to the surface.

A transverse section of the *black substance* presents small apertures, generally round (fig. 102, 1) (canals of whalebone) and placed at regular distances, which are very often seen to be filled with a dark substance. Around each of these apertures a large number of concentric layers is observable, of which the exterior ones, however, do not remain circular, being so much flattened by those of the adjacent canals, that they take up almost the whole space between these canals (that is, the round apertures just mentioned) (fig. 102, 2).

The thickness of these concentric plates is almost the same as that of the plates of the grey portion. Between these also, small dark spots may be seen (fig. 103), which are, however, still much smaller than those of the grey portion, and have the appearance either of round points, or of small lines, which are found most numerous near the little canals, around which the plates are situated. They are also rendered transparent by turpentine. In addition they present a large number of very fine lines, which proceed like rays from every whalebone-canal, and appear to extend through all the surrounding plates.

A longitudinal section of the black substance presents dark grooves, tolerably broad, running parallel to one another, and placed at regular distances. They continue visible in the whole length of the section, and have no mutual communication whatever by lateral branches (fig. 104, 1). These little canals, which run uninterruptedly, and through the whole length of the whalebone in the longitudinal direction, appear almost exclusively to produce the black colour of the striated substance. We call them whalebone-canals. Every one of these canals is filled with a series of oblong fat-cells (figs. 104, 2, and 105, 4), and a black, finely granulated matter lies between the wall of the cells and the canals (fig. 105, 5). If the section has not been made completely parallel to the direction of the whalebone-canals, a few of them are seen cut off (fig. 105, 3).

When a longitudinal section of the concentric plates of a whalebone-canal is seen under a higher magnifying power (fig. 105), we observe that these plates (1) are nearly similar to those of the grey substance. Between the plates, irregular, elongated, and dark coloured spots (2) are now also visible, which may be considered as little spaces between them. As it is very difficult to make the section completely parallel to the direction of the concentric plates, the object presents transverse lines, which are all succeeding sections of the several concentric plates (3).

soluble in ether and alcohol, 3.85 per cent. When boiled with water for 24 hours, a substance is dissolved out, of which the properties resemble those of gelatine, although differing from it in some respects. The quantity of this substance ob-

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When tearing off longitudinally a part of the black substance, it not unfrequently happens that a single canal is obtained separately, surrounded by its concentric plates.

A very thin piece of the *grey substance*, cut through transversely, after having been for five hours in a strong potash ley, has assumed a very dark appearance, and its laminar structure has become far more distinct. When water is added, it becomes much paler, and the plates become detached from one another to such an extent that the whole resembles a beautiful net of fibres, with oblong meshes, which become still looser on the addition of more water, without, however, being dissolved. In these meshes large elliptic cells are to be seen at irregular distances from one another.

A very thin piece of the grey substance cut through longitudinally along the edge, after having been left in a strong potash ley for five hours, appears also to consist of fibres, which are united with each other, and form oblong meshes. In each of these meshes we observed an oblong and dark coloured spot (cavity ?).

A very thin piece of the grey substance, cut parallel to the broad surface, is only slightly changed, after having been kept in a strong potash ley for five hours. After water has been added the substance remains shapeless, although here and there a series of tolerably large sized, pale cells is to be seen bordering each other, and containing kernels. We saw, also, dark coloured, bent lines, united together in the form of meshes.

When a somewhat thicker piece of the grey substance, cut through transversely, has been left in a strong potash ley for five hours, for twenty-four hours, and also for ten days in succession (in the latter case, however, the access of the atmosphere was not prevented), and water is then added, the texture of the meshes is much loosened, and presents a cellular appearance, similar to that of the merenchymatic cells in plants (fig. 106, *a*). By pressing and rubbing the cells a little, they yield easily, and appear isolated like ovate cells, which, revolving round their longer axis, retain their form, and still contain, especially in one spot, something granular, which may, perhaps, be considered as the remains of a nucleus (fig. 106, *b*).

When a very thin piece of the *black substance*, cut through transversely, is left in a strong potash ley for five hours, it is darkened in appearance. The boundaries of the concentric plates are very distinct ; here and there they seem to pass into each other. Between the plates the small dark spots are visible. When water is added, the plates often recede a little from one another, and then they have the appearance of a net, with very long, but narrow meshes.

A very thin piece of the black substance, taken parallel to the surface, presents hardly any change after it has been kept five hours in a strong potash

tained amounts only to 1.88 per cent. Whalebone contains 1.17 per cent. of inorganic substances, which appear to consist of the chlorides of sodium and magnesium, sulphate of lime, phosphate of lime, oxide of iron, phosphuret of iron, sulphuret of iron, and silica. It contains no phosphorus, but the proportion of sulphur in it is constant, and amounts to 3.6 per cent.

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ley. When water is added, the concentric plates recede from one another and assume the appearance of a net, as in the grey substance.

In the medullary canal nothing is seen but a dark, granular substance.

A transverse section of a very thin piece of the black substance, after having been kept for forty-eight hours in a strong potash ley, exhibits the concentric plates around the medullary canal very distinctly. On the addition of water, the plates around some of these canals recede from one another, and assume the appearance of a net. Others of these canals are isolated with the whole of their concentric plates (fig. 107). When rubbed, these concentric plates give way, first at the outside, and either one by one, or several at a time (fig. 108), and place themselves upon their broadest surface, which at the same time indicates the breadth of the little object (fig. 109).

These turned plates present no distinct structure; they are very pale, and must be considered as taken parallel to the surface, because they have turned themselves in that direction.

A thicker piece of the black substance, cut off either transversely or longitudinally, when left in a solution of potash for twenty-four hours, presents a dark appearance. On the addition of water its structure becomes loosened and cellular, and when rubbed it is wholly converted into isolated cells, which do not differ from those of the grey substance.

It follows from these observations that whalebone consists of thin plates, which are situated partly parallel to the surface, and partly around parallel and continuous little canals in a concentric position, and that these canals contain fat-cells, and a black, granular substance. Further, that between these plates small spaces are left, which, in reference at least to the concentric plates, are probably in communication with the whalebone-canals by means of the radiating lines before mentioned:—that each little plate consists of a multitude of flattened cells, of which the contents are dissolved by potash;—that when water is then added, these cells swell, and become isolated when they are not cut through, but that if they are cut through,—as happens when very fine sections are made,—they remain connected together, and present a reticulated appearance. Hence it follows, that the wall of the cells resists the action of potash much longer than the contents and the binding material.

Chemically considered, we have to distinguish in whalebone, 1° the cell-walls, 2° the contents of the cells, 3° the binding material, the two latter being only in comparatively small quantity, 4° fat-cells, 5° a black, granular substance. (Donders and Mulder.)

When whalebone is treated with strong sulphuric acid, it is converted into a mucilaginous substance, which is for the greater part dissolved by water.

By nitric acid it is converted into xantho-proteic acid, by hydrochloric acid into humate of ammonia. Strong acetic acid renders it gelatinous, and dissolves it at last. On adding ammonia to the liquid, van Kerckhoff obtained a precipitate of bi-oxide of protein, $C^{40}\,H^{31}\,N^{5}\,O^{14}$.*

Under these circumstances this bi-oxide of protein cannot be a product of decomposition, but it must either be a constituent of whalebone, or at least be formed in a very simple manner.

When the solution so obtained was treated first by potash and subsequently with chlorine, van Kerckhoff obtained the same compound of chlorine which is spoken of at p. 510, as being prepared from horn under the circumstances there mentioned,† and having the composition $C^{40}\,H^{31}\,N^{4}\,O^{17}$, $Cl\,O^{3}$.

By the protracted action of chlorine upon finely powdered whalebone, a chlorite of bi-oxide of protein was obtained, having the following composition: $C^{160}\,H^{124}\,N^{20}\,O^{65}\,Cl^{3} = 4\,(C^{40}\,H^{31}\,N^{5}\,O^{14}) + 3\,Cl\,O^{3}$.‡

		Found.	Atoms.	Calculated.
*	C	53.68	40	53.36
	H	7.21	31	6.75
	N	14.39	5	15.45
	O	24.72	14	24.44

Scheikundige Onderzoek. Deel II., p. 396.

		Found.	Atoms.	Calculated.
†	C	46.72	40	46.34
	H	5.79	31	5.87
	N	11.49	4	10.75
	O	29.94	20	30.33
	Cl	6.06	1	6.71

Scheikundige Onderzoek. Deel II., p. 403.

		Found.	Atoms.	Calculated.
‡	C	48.11	160	48.63
	H	6.03	124	6.15
	N		20	14.08
	O		65	25.85
	Cl	5.32	3	5.29

This chlorine compound was dried at 239° F. At 212° F. its composition is: $2\,(C^{40}\,H^{31}\,N^{5}\,O^{14}) + 3\,Cl\,O^{3}$.

This again proves that bi-oxide of protein either pre-exists in whalebone, or at least is easily produced from it.

Van Kerckhoff found the composition of whalebone in its natural state to be:

$$C^{106}\ H^{82}\ N^{14}\ O^{34}\ S^{3}.*$$

Which formula is equivalent to—

$$2\ (C^{40}\ H^{31}\ N^{5}\ O^{14}) + S^{3} + 2\ (C^{13}\ H^{10}\ N^{2}\ O^{5}).$$

If, however, we abandon the idea of any binding material, and confine ourselves to the cell-wall alone,—which we are apparently equally entitled to do with regard to whalebone as to horn and hair,—and if we at the same time recall to our mind the properties of whalebone, its composition seems to be represented by the following formula:—

$$C^{80}\ H^{62}\ N^{10}\ (O^{26}\ S^{2}).\dagger$$

This formula is in complete accordance with the composition of whalebone, as found by van Kerckhoff, and explains the greater part of the products of decomposition which he obtained from it; and, moreover, this idea is seemingly not opposed by any of the properties of whalebone, as far as they are yet known. It is equal to or may be expressed by

$$2\ (C^{40}\ H^{31}\ N^{5}\ O^{12}) + O^{2}\ S^{2}.$$

GG. Hair.

Hair is essentially different from all the tissues of which we have hitherto treated; it has therefore particular claims upon our attention.

*

	Found.	Atoms.	Calculated.
C	51.86	106	51.91
H	6.87	82	6.56
N	15.70	14	15.88
O	21.97	34	21.78
S	3.60	3	3.87

†

	Atoms.	Calculated.
C	80	52.43
H	62	6.64
N	10	15.19
O	26	22.29
S	2	3.45

The origin of hair is a cytoblastema, capable of assuming the cellular form, and secreted in a depression of the skin, in which a vascular tissue is found. New cells being continually produced at the lowermost part of the cavity, those already existing are continually lifted up, and thus gradually raised, through an aperture, above the surface of the epidermis; in this manner the protruding part is continually elongated.

The series of cells, which are tolerably distinct in the roots of the hairs, are not so in the hair itself of several animals. The whole of the hair is covered with an epithelium, which, when treated with sulphuric acid, is loosened from the surface in the form of plates or layers (fig. 111). This epithelium consists of flattened cells, fitting closely together, and thus the bent transverse lines, which are easily distinguished on hair, are found where these cells are joined together. The cells immediately below these, of which the main body of hair is composed, form small flat plates (fig. 112, *c*) or fibres (*b*), which are united together into bundles (*a*). Of the cells which were situated in the axis of the hair, in most cases only traces are left (fig. 113). The substance of which hair chiefly consists, and which has the form of small plates or fibres, is called the *cortical matter* of hair, that in the centre the *medullary matter*; but these names would be more properly replaced by *hair-tissue* and *medulla*, because the former constitutes the principal part of hair. The latter is often wanting, or does not extend, without intermission, through the whole length of the hair. The exterior, or chief substance of hair consists of parallel bundles, which are partly placed upon one another. When a hair is put into strong sulphuric acid, a little rubbing is sufficient to detach the epithelium in the form of plates (fig. 111), and the ligamentary substance, by which the fibres are held together, is dissolved; the fibres separate from each other in the shape of bundles, and the surface of the hair becomes rough. By continued rubbing these bundles are divided into thinner and smaller fibres or plates, a fact which leaves no doubt that they are small, compressed, and elongated cells. We have, however, failed in the attempt to make them swell into distinct cells.

The primary fibres of hair are, according to van Laer, a compound of protein and sulphur, viz.:—

$$C^{40}H^{31}N^{5}O^{12}S^{2}$$

Hair, therefore, contains 5 per cent. of sulphur.

The substance, by which it is supposed that these fibres are united together, cannot be obtained separately; for every substance employed for that purpose, would decompose it. It is probable that the medullary substance, which forms the central part of hair, has the same composition as the primary fibres—since this medullary substance consists of unaltered hair-cells, while the hair-fibres are produced by the simple transformation of these cells.*

* When *hair* (black hair from the human head) is kept for three hours in potash dissolved in one fourth part of water, it has a dark appearance, but nothing can yet be distinguished. On the addition of water, the hair becomes transparent and the edges particularly so; at some spots vesicular swellings are produced, having granular contents, which flow out and are dissolved. The hair fibres are here and there marked with elongated dark lines. The vesicular swellings are not visible on all hairs; but where they are, they are so distinctly defined, that they might be considered as cells, filled with large granules. When more water is added, the edges of the hair are more easily distinguished from the tissue underneath, which is very much swollen, and these appear to consist of a number of layers, placed one upon another. On some spots plates become detached from the surface, in a longitudinal direction from the base towards the point;—protruding outwardly, but still fixed by their lower part (fig. 110, 1).

After having been kept for four hours in a strong solution of potash, they have a dark appearance, but are not swollen. After the addition of water, they swell very much, and the epithelium becomes very light coloured and transparent.

Hair from the beard, which had been kept for four hours in a strong solution of potash, behaved like the former. When water is added, the whole swells very much, the epithelium is torn open, the contents are dissolved, and if sulphuric acid is now quickly added, the remaining epithelium becomes quite distinct. This epithelium, which consists of a protein-compound, differs from the epidermis in this, that the plates are not expanded into cells.

When hair from the beard has been lying in strong sulphuric acid for two hours and a half, it has become rough on the surface, by the protuberance of the epithelium, which when rubbed becomes detached in the form of large plates, after which the transverse lines of the hair may be distinctly recognised (fig. 111, *a*). By continued rubbing the several plates of epithelium are entirely isolated (*b*). By pressure, the whole of the epithelium is loosened in the form of large plates,

Van Laer, who has analysed hair, has found that its composition is represented by the formula $C^{53} H^{41} N^8 O^{17} S^2$.* If from this we subtract the formula of the sulpho-protein compound, there remains $C^{13} H^{10} N^3 O^5$, representing the composition of the supposed binding material; a formula which has some analogy to that of gelatine.

I formerly coincided in this view of van Laer. Since the other horny tissues have been examined, however, and

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and the substance below it (secondary hair-bundles, fig. 112, *a*) is divided into fine fibres (*b*), or into plates (*c*), which are somewhat swollen by the action of the sulphuric acid.

Black hair from the head, which has been kept for twenty-four hours in a strong solution of potash, appears very much swollen and very soft. On water being added, the epithelium and the tissue of the hair itself float away and are for the greater part dissolved, without assuming the cellular form; the medulla is left behind isolated, appears dark by transmitted light, and presents a somewhat cellular structure (fig. 113, *a*). Black hair from the beard, kept for twenty-four hours in potash ley, presents precisely the same reactions (fig. 113, *b*).

In the skin of a full-grown fœtus we always find two follicles of hair (lanugo) placed side by side; the hairs originating from them run parallel, then cross one another, and pierce through the epidermis in close vicinity. (Donders and Mulder.)

* Van Laer in Scheikund. Onderz. Deel I. p. 177.

	Found.	Atoms.	Calculated.
C	50.65	53	50.12
H	6.36	41	6.33
N	17.14	8	17.52
O	20.85	17	21.03
S	5.00	2	4.99

$= C^{40} H^{31} N^5 O^{12} S^2 + C^{13} H^{10} N^3 O^5$

The analyses made by Scheerer (Annal. der Pharm. 1841, Oct. p. 55), yielded about the same proportion of carbon and nitrogen, viz.:—

	I.	II.	III.
C	51.53	50.65	50.62
H	6.69	6.77	6.61
N	17.94		
OS	23.84		

We must, however, introduce into this composition 0.53 per cent. of phosphorus, and thus the formula for hair becomes 12 ($C^{53} H^{41} N^8 O^{17} S^2$) + Ph, combined with sulphate and phosphate of lime, oxide of iron, chloride of sodium, sulphate of magnesia, and some substances soluble in alcohol and ether, viz., margarine, margaric acid, elaïne, and lactate of ammonia.

my knowledge of them has increased, I am of opinion, that such a view of the constitution of hair does not admit of defence. For, in the first place, chemical reaction never gives any indication of the presence of such a binding material. Secondly, a microscopical examination of hair affords no proof of the existence of an appreciable quantity of such a substance. Thirdly, the properties of hair are not in accordance with the presence of any binding material—for instance, hair is not affected by strong acetic acid, which acts upon all other horny tissues, and even dissolves several of them completely. Lastly, every property of hair can be accounted for in a much simpler way, namely, by giving to its composition the formula 2 (C^{40} H^{31} N^6 O^{12}) S^3, which represents a mixture of bi- and tri-oxide of protein, in which five equivalents of oxygen have been replaced by two equivalents of nitrogen, and three equivalents of sulphur, in this manner—

$$C^{80}\,H^{62}\,N^{10}\left(\frac{O^{24}\,N^2\,S^3}{O^{29}}\right)^*$$

$$= C^{40}\,H^{31}\,N^5\,O^{14} + C^{40}\,H^{31}\,N^5\,O^{15}$$

$$= 2\,(C^{40}\,H^{31}\,N^5\,(O^{12}\,N\,S))\,S$$

It is necessary that we should give an explanation of this view, which must certainly not be regarded as proved, but seems at present more probable than any other.

First, it is to be remarked, that protein can lose an equivalent of nitrogen and take oxygen in its place; for we know that there is a combination, which contains four instead of five equivalents of nitrogen.

Again, the reaction which chlorine exercises upon hair, is one of the strongest proofs in support of the view above pre-

* This formula completely represents the composition of hair, as found by analysis.

	Atoms.	Calculated.
C	80	50.92
H	62	6.45
N	12	17.64
O	24	19.99
S	3	5.00

sented. The form of the hairs remains thereby entirely unaltered, and they lose but little in weight, they only become brittle. This reaction is wholly different from that exercised by chlorine upon horn and whalebone.

When a current of chlorine is passed for a long time through water, in which hair is suspended, chlorite of protein is produced.* When this chlorite of protein is decomposed by ammonia, and the sal-ammoniac produced is extracted with alcohol, the remainder is tri-oxide of protein, in the anhydrous state.†

This chlorite of protein, arising from the action of chlorine upon hair, may be regarded as the only essential product of this reaction. Although the hairs are rendered brittle by this operation, they retain their form entirely. Hair therefore contains a protein compound, which by the action of chlorine loses two equivalents of nitrogen, and three equivalents of sulphur, in the place of which two equivalents of chlorous acid ($Cl\,O^3$) enter into combination with two equivalents of protein: this conversion is effected, without the form not only of the hair fibres, but even of the whole hair itself, being in the least changed. It is not difficult to give an explanation of this conversion. Two equivalents of nitrogen are combined with six of hydrogen, and two equivalents of chlorine with six of oxygen. Whilst, therefore, six equivalents of water are decomposed, chlorine converts hair into

* Van Laer, in Scheikundige Onderzoekingen. Deel I. p. 160.

	I.	II.	III.	IV.	Atoms.	Calculated.
C	49.02	49.67	48.15	48.07	40	48.76
H	6.08	6.08	5.94	5.93	31	6.16
N	14.09				5	14.11
O	18.09				12	19.13
$Cl\,O^3$	12.61			12.62	1	11.84

I. and II. were obtained from human hair, III. and IV. from black horse hair.

† Van Laer in Scheik. Onderz. p. 161.

	Found.	Atoms.	Calculated.
C	52.35	40	52.44
H	6.67	31	6.64
N	15.07	5	15.19
O	25.91	15	25.73

ammonia and the chlorite above-mentioned, the sulphur being separated.

When hair is dissolved in a weak solution of potash, and the liquid then mixed with a little acetic acid, protein is precipitated, but in so very small a quantity that it cannot be considered as an essential constituent of hair. When this protein is removed and an excess of acetic acid then added, a precipitate is obtained, which is bi-oxide of protein, $C^{40}\,H^{31}\,N^{5}\,O^{14}$. The oxygen of the potash replaces the sulphur of the hair, and for every equivalent of potash (Ka O) one equivalent of sulphuret of potassium (Ka S) is produced, and thus oxygen is liberated, to form oxide of protein. This is also explicable on the view which I entertain of the composition of hair, as mentioned before, with this exception that it does not explain what becomes of the two equivalents of nitrogen. If these are converted into ammonia (which is actually expelled during this decomposition) by the simultaneous decomposition of water, then there remains an excess of oxygen—for whilst the six equivalents of hydrogen, required for producing ammonia, are taken up, six equivalents of oxygen are liberated. Now, the three equivalents of sulphur contained in the hair liberate three equivalents of oxygen from three equivalents of potash, and as only four equivalents of oxygen are required to convert the whole of the protein into bi-oxide of protein, five equivalents of oxygen are left, which cannot be accounted for, and therefore require to be further sought after.

As regards, finally, the protein compound, which contains four equivalents of nitrogen instead of five, we must consider that bi-oxide of protein,—not only that obtained from hair, but also that which appears to exist in horn ready formed, and which is easily produced from whalebone.—undergoes an important change through the influence of chlorine. When protein is thrown down by a little acetic acid from a solution of hair in potash ley, and a current of chlorine is then passed through the liquid, holding bi-oxide of protein in solution, a precipitate is obtained, which consists of $C^{40}\,H^{31}\,N^{4}\,O^{17}$ +

$Cl\,O^3$.* This substance differs from protein, both by its containing chlorous acid, and also by having five equivalents of oxygen more and one equivalent of nitrogen less. It is produced from the bi-oxide of protein, by the decomposition of water and the formation of ammonia, in the following manner:—

$$C^{40}\,H^{31}\,N^5\,O^{14} + H^3\,O^3 = C^{40}\,H^{31}\,N^4\,O^{17} + N\,H^3$$

The first of these two combines with chlorous acid, $Cl\,O^3$, and the ammonia unites with the hydrochloric acid, which is present in the solution, to form sal-ammoniac ($N\,H^4\,Cl$).

Although this substance is an artificial product, it is nevertheless of importance to our knowledge of protein, because it suggests the possibility, that protein may absorb more oxygen and lose part of its nitrogen; and as in this very way it may happen in the organism, that protein disappears from the animal body, viz., by absorbing oxygen, it is possible, that the last-mentioned substance,—certainly free from chlorous acid,—may exist in the products of disease.

When hair is boiled in dilute sulphuric acid, it is changed into humate of ammonia, and formic acid is expelled during boiling; which is the same change that protein undergoes by putrefaction, as mentioned in p. 47. By hydrochloric acid it is converted into humate of ammonia and sal-ammoniac; by nitric acid into xantho-proteic acid. Hair resists the action of strong, boiling acetic acid, in which respect it differs from the other protein compounds—from fibrin, albumen, and casein, and also from whalebone, horn, and epidermis.

By boiling water, even in Papin's digester, hair is long left unchanged; when at last decomposed in this manner, a red-coloured extract occurs among the other products, which are yet but imperfectly known.

* Van Laer in Scheik. Onderz. Deel I. p. 171.

	I.	II.	Atoms.	Calculated.
C	46.16	45.83	40	46.34
H	5.74	5.85	31	5.87
N		11.25	4	10.75
O		24.30	17	25.78
$Cl\,O^3$	11.89	12.77	1	11.26

See above, p. 511 and 518.

It would appear that the colour of hair is not caused by any peculiar substance.

Hair from various animals (wool, &c.) differs by small admixtures, but the chief constituents are the same in all.

Since, then, on the one hand the composition of the epidermis and of the nails is so similar to that of hair, and on the other hand, there are such material differences in their properties,—the latter, for example, being almost insoluble in strong acetic acid, in which the two former are readily soluble,—the constitution—the composition of hair must materially differ from that of horn and whalebone. Scheerer's conclusion, therefore, that they are all identical, is incorrect. For the sake of comparison, I append the results, obtained by the analysis of each of these bodies.*

In consequence of what has been said before, I think that there are grounds for the present to assume for these substances the following formulæ:—

Whalebone, ... $C^{80}\ H^{62}\ N^{10}\ O^{26}\ S^2$

Hair, ... $2\ (C^{40}\ H^{31}\ N^5\ (O^{12}\ N\ S))\ S$

Horn, ... $2\ (C^{40}\ H^{31}\ N^5\ O^{14}\ S) + N\ H^2$

Nails of cows and horses, ... $C^{40}\ H^{31}\ N^5\ (O^{12}\ N^2) + 2\ (C^{40}\ H^{31}\ N^5\ (O^{12}\ S^2))$.

It is as yet impossible to determine in what manner the atoms of sulphur are arranged, and I shall willingly give up the above theoretical view for any one that is better. I believe, that at present it gives a simple explanation of what it is intended to explain. We must, however, regard our knowledge of these bodies as yet in its infancy. Any one who should take this view as a proof, that I regard protein as a radical, would incur the reproach of having forgotten that I have often insisted, and do here again insist upon the

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	Horse-nails.	Epidermis.	Horn.	Whalebone.	Hair.
C	51.41	50.28	51.03	51.86	50.65
H	6.96	6.76	6.80	6.87	6.36
N	17.46	17.21	16.24	15.70	17.14
O	19.94	25.01	22.51	21.97	20.85
S	4.23	0.74	3.42	3.60	5.00

complex nature of protein (p. 309). It is my opinion, that one of the several members that constitute this group, and not the whole group, changes its composition, taking up oxygen, or sulphur, or nitrogen. In the same manner we designate benzoic acid by the formula $C^{14} H^5 O^2 + O$, but surely nobody will be so devoid of chemical sense, as to imagine that the elements of this combination are really thus arranged.

There is one additional conclusion to be drawn from what has been mentioned here, viz., that in all these tissues which consist of unchanged cells, we find bi-oxide of protein as the proto-type, which tends to confirm what has been said at p. 488, on the membranes of animal cells.

If the composition of horny tissues is actually that which we have stated, then it will be unnecessary to enter into any further explanation of their production, after what we have said at page 341, regarding the presence of bi-oxide of protein in the blood.

As to the source whence the sulphur of these tissues is derived, this is easily explained. Sulphur and phosphorus are constituents of the protein compounds, which exist in the vegetable or animal food, and thus both enter into the body. Now, as in every respiration, a small quantity of these compounds of protein, sulphur and phosphorus is consumed, and oxide of protein, &c. is produced, phosphoric acid must be formed at the same time, and sulphur must be set free. The phosphoric acid combines with some alkali that is present, and forms an alkaline phosphate, which is discharged in the urine.* The sulphur contained in these tissues, is therefore to be traced directly to the sulphur, which is continually supplied as food along with the protein.

It would appear that this sulphur, like the nitrogen, may replace part of the oxygen of the protein compound, but that in some it actually behaves as sulphuret of ammonium, in so far that this salt evaporates by exposure to the air so as to impart its smell to the tissue, and to make it have the same reaction upon metallic salts as sulphuret of ammonium.

* This cannot be generally the case, inasmuch as the urine of herbivorous animals rarely contains any considerable quantity of phosphoric acid.—*J.*

HH. Tortoise-Shell.

This remarkable tissue, which may be called an epithelium of the shell of the tortoise, is intimately connected with those we have been treating of. It consists of flat, densely packed and compressed cells (fig. 114 and 115), which, however, resume with great difficulty the cellular form in which they appeared when newly developed. A number of these flattened cells are united into a plate, and a great quantity of such plates are piled upon each other.*

* *Tortoise-shell*, cut parallel to the internal surface, presents curved lines, running irregularly. On a transverse section we see some small plates overlying each other, and these plates are marked with a large number of dark, curved lines. When pressed, these little plates recede from each other; and every one of them presents traces of straight lines, whence they appear to consist of still thinner plates. A longitudinal section presents these thicker plates likewise.

After a section, taken parallel to the surface, has been kept in a strong solution of potash for six hours, it presents here and there oblong outlines, and long dark lines. The addition of water produces no visible change. The pieces are still hard, and hence the action, exercised by potash upon this tissue for six hours, is insufficient to soften it.

After a transverse section has been kept in potash ley for an equal period, nothing particular can be discovered. When water is added, it becomes clearer and the lines are far more distinct. They are placed close together, interrupted and interwoven at short mutual distances. On the edges of the pieces small plates give way, which are very transparent, and gradually lose their angular appearance. On the surface of a piece these lines have the appearance of meshes, in the same manner as in whalebone, &c.

Pieces, taken parallel to the surface, after being kept in strong sulphuric acid for six hours, have become very gelatinous, swollen and transparent, having sharply defined, curved lines, at great distances from one another. It is only with difficulty that by pressure we can loosen some fragments. The addition of water produces only a slight change.

When a very thin transverse section has been kept in a strong solution of potash for 24 hours, and water is then added, it presents the appearance of cellular structure; the cells are elliptic, and still a little angular; they partly cover one another, and do not separate, and hence they take the appearance of a net-work with oblong meshes (fig. 114).

After having been kept in a strong potash solution for 48 hours, on water being then added, beautiful globular cells make their appearance (fig. 115), having a light brownish colour, no kernels, but somewhat granular contents, which do not completely disappear by the prolonged action of water. The cells become now isolated, and we perceive between them a small quantity of a granular substance.

Tortoise-shell, when analysed in its natural state, leaves half a per cent. of ash, and has the composition given below.*

When boiled in acetic acid, it becomes gelatinous, and if it is then diluted with water, filtered, and carbonate of ammonia added to the solution, an abundant floccy precipitate is produced. When a saturated solution in acetic acid is filtered while warm, a white precipitate also subsides by simple cooling, and the liquid remains milky. The addition of basic acetate of lead to the clear solution in acetic acid produces an abundant white precipitate.

After being treated with strong boiling acetic acid, a large portion of the tortoise-shell is left undissolved.

It is soluble in potash-ley, and a small quantity of acetic acid added to the solution produces a white precipitate, which resembles the second precipitate mentioned above in this respect, that it adheres strongly to the glass and is very coherent itself, as if it were a resinous substance. When more acetic acid is added, the quantity of the precipitate is not increased.

The chemical properties of tortoise-shell I have not further examined. It appears, however, from the above, that it differs from all other horny tissues.

II. Gelatinous Tissue.

As there exists in plants a fundamental substance, of

Tortoise-shell, when kept in strong sulphuric acid for six months, has the same appearance as that which has been in potash ley for 24 hours. The cells are still not separated from one another, but cohere together, although they are swollen. Between the swollen cells we perceive continuous canals, with brownish contents.

When kept in nitric acid for six months, nearly the whole is dissolved, only a few shapeless fragments remaining. (Donders and Mulder.)

* Treated with ether and alcohol, and dried at 266° F. :—

C	54.89	54.75
H	6.56	6.63
N	16.77	16.46
O	19.56	
S	2.22	

which both the cells themselves and the parts formed from cells are built up (cellulose), so the animal body contains a universal material, which we have distinguished before by the name of gelatinous substance (p. 319). We have, however, already made the remark, that unlike the cellulose in plants, it is not the compound from which the original cells of the animal body are built up (p. 320).

But the doctrine of tissues teaches us, that it is by no means proper to class together all the parts of organs that produce glue by boiling. Like cellulose in plants, the gelatinous substance in animals assumes different forms, and unites with other substances to form tissues of an entirely peculiar character.

We meet as a chief constituent of the organism, a tissue consisting mainly of gelatinous substance and of *ligamentary tissue*, formerly called cellular tissue, which unites together the component parts of almost all organs. When duly developed, however, it does not consist of what may be called cells, any more than the spiral vessels of plants are to be called cells (see p. 100). It is composed of thread-like little cylinders, running in a vermicular direction (fig. 116 and 124), and in most cases united into bundles by means of a binding material, which is either shapeless or granular. These bundles are again collected into larger bundles or membranes, of which the threads are distributed either in every direction through one another, as is the case in the skin and in the so-styled cellular tissue below the skin; or parallel to each other, as in the tendons, and in many serous and fibrous membranes. Acetic acid renders these threads transparent and gelatinous (fig. 121, 1). Some, after being treated with acetic acid, appear involved with other threads, bending over the surface of the former in various directions, which are most frequently spiral, but sometimes completely circular. Between the threads of the ligamentary tissue some others are visible, running often parallel to them (fig. 121, 2), which are also not rendered gelatinous by acetic acid, and seem not to differ from the involving threads. These parallel ones are in every respect similar to elastic tissue.

This alone is a sufficient reason why the composition of the gelatinous tissue cannot be regarded as a simple one, and cannot possibly be entirely identical with that of gelatine.

The fact, therefore, that Scheerer has obtained the same results by the elementary analysis of tendons, &c., as I got from gelatine (p. 322), shows the limits of the accuracy of elementary analyses. Scheerer has analysed a mixture of ligamentary tissue, interwoven with a little elastic tissue.* The loose cellular tissue, which holds the secondary bundles of tendons together, contains also vessels and fat tissue, of which the cell-walls are left behind.

It is difficult to ascertain the real composition of ligamentary tissue, as it exists in the organism, because there is not one tissue in which it is present in a completely pure state. All we know about it, however, concurs in inducing us to assign to it the same formula as to gelatine, viz., $C^{13} H^{10} N^2 O^5$.

It has the same properties as gelatine, except that it is insoluble in cold water, and is entirely converted into gelatine by boiling. Of this gelatinous tissue, there are two varieties, the *shapeless*, and that which has a *definite form*.

The *former* is composed either of bundles, united together like a net, or of thin plates, which form cavities cohering together, but leaving large apertures between. This is the variety which unites the skin with the muscles that bind together the secondary bundles of muscles, those of the nerves, and tendons, and the lobes of the glands,

* Winkler has made analyses of the tendons of a cow, previously treated with cold water and boiled with alcohol and ether, (Scheik. Onderz. Deel III.) and obtained

C	49.68
H	6.64
N	17.94
O	25.74

—which is nearly the composition of gelatine. Although the number of elastic threads in tendons is but small, they nevertheless exist. The above result shows satisfactorily, that Scheerer has obtained too much hydrogen, and that what he has asserted in Canstatt's Jahresbericht is incorrect. With regard to the gelatinous tissue, we would further refer to what has been mentioned before, page 320.

and which we have just designated by the name of ligamentary tissue. In this tissue the fat cells are enclosed.

The *latter*, or that with a *definite* form, is subdivided into two kinds, one contractile, and the other not contractile. Those belonging to the first kind, are the skin, more especially that of the scrotum, the corpora cavernosa, the longitudinal and annular skin of the veins and lymphatic vessels. Besides the threads of ligamentary tissue, they contain also those of elastic tissue, in greater number than the non-contractile kind. To the latter class belong the tendons—which consist of bundles running parallel to each other, and united together by a looser tissue, having the same chemical properties as the tendons themselves; also, the ligaments, which are of a similar structure—excluding, however, the elastic or intervertebral ligaments—the cartilages between the joints,(?) the fibrous membranes—to which belong the sclerotica which covers the kidneys, the ovaries, the spleen, &c.—the dura mater, the membrana tympani, the valvules of the veins, the lymphatic vessels and the heart, the neurilema, the fasciæ of the muscles, the periostium and perichondrium, the tunica nervea of the intestines, &c., the serous membranes, the pia mater and choroidea. The latter are, comparatively speaking, intermixed with much smaller quantities of threads of elastic tissue. This tissue, however, seems to be never anywhere wanting.*

* *Loose cellular tissue between the muscles of the thigh of a full-grown man.*—It presents very long, fine and bent tissues, running parallel and united into bundles (fig. 116). When put into acetic acid, they swell very much, and become very pale, and even invisible. Here and there they alternate with fibres of elastic tissue, which are very long and run in all directions, sometimes even entirely straight. A single bundle of the ligamentary tissue presents three globular parts, placed in contact with one another, and united by mutual contractions. There are, therefore, three circles of elastic tissue rolled round the thread.

After having been kept for four hours in a strong potash ley, no change has taken place; only here and there a little fibre is seen with granular swellings. By the addition of water, the whole is dissolved, except a few long, thin, and bent threads of elastic tissue (fig. 117).

Loose cellular tissue below the fascia lata of the thigh, being kept in potash for five hours, presents elliptic apertures inclosed on all sides by a thick rim. The edges consist of some distinct fibres, whereas in the elliptic spaces,

All these kinds of ligamentary or gelatinous tissue originate from little globules, with a kernel in which one or two nucleoli are to be seen. The cells formed from these are elongated in two directions, and are thereby converted into

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granular contents are found (fig. 118). On the addition of water the elliptic apertures disappear first, and subsequently the whole tissue, and after everything else is dissolved, there remain long, slender, transparent, and curled fibres, of elastic tissue.

The external lateral ligament of the sub-maxillary joint, having been kept for six hours in potash, presents the same appearance as the ligamentary tissue below the fascia just mentioned. After the addition of water, elastic fibres again make their appearance.

The skin of the thigh of a full-grown man, kept four hours in weak acetic acid.—The fibres of the cellular tissue below that part of the epidermis which contains kernels, have become swollen and very transparent. Fine, bent, short, and elastic fibres are visible, and they become stronger and longer in proportion as they are seen farther from the surface (fig. 119). By their manifold ramifications and reflections they there form a net, of which the meshes are quite transparent, and filled with the swollen cellular tissue. At a greater depth the threads become longer, thicker, less in number, and leave wider spaces between them, in which fat tissue is placed. Here are situated the perspiration glands, of which the spiral excretory tubes penetrate the skin; and, further, the sebacic glands and the follicles of the hairs.

After having been kept in potash for fifty hours, on water being added, there remains a large number of elastic fibres, which are broader than those which we saw in the tendons and in other parts, but exhibit their peculiar curlings and ramifications.

The skin of a fœtus kept in a strong solution of potash for seven hours.—Nothing distinct can be seen. After water has been added, there remain attached to part of the edge of the little object, a number of elastic fibres united with one another in the shape of a net. In the middle of this part, as in the cellular tissue below the fascia, we observed roundish apertures, defined by thick rims. In these apertures dark coloured contents are found, which, after being somewhat more diffused through and acted upon by the water, are divided into a granular substance and afterwards dissolved.

The skin of a fœtus, kept in acetic acid, presents thin elastic fibres, which are usually very short, being swollen in some parts, which arises from the kernels out of which they have been formed.

The solid bundles of the fascia lata of the thigh, after having been kept in potash for six hours, present fine fibres, running vermicularly and parallel to each other, upon which are placed at right angles broad and transparent bundles, which appear to be enclosed in little tubes.

The vermicular fibres of the fascia belong to the elastic tissue. They may be separated from each other by tearing them, and then very broad fibres are obtained. After they have been treated with potash for fifty hours, and water has been added, the elastic fibres alone remain.

thread bundles, from which the cell kernels at last disappear. (Schwann.) According to Henle, however, it is not proved that these threads have previously been perfect cells. On the contrary, he thinks it more probable that the elastic

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A transverse section of the (dried) tendon of the semitendinosus (fig. 120) presents, after water has been added, secondary bundles of tendons of variable size (1), held together by a loose cellular tissue (2), having a granular intercellular substance. In this loose cellular tissue we perceive sections of blood-vessels (3), around which chiefly fat-tissue (4), is found. Every secondary bundle presents a great number of elongated little points, at regular distances from each other; these points are the sections of the threads of elastic tissue.

A longitudinal section made through the centre of the tendon of the dried semitendinosus presents transparent bundles, running parallel to each other, consisting of thin bundles of tendons, bent in a vermicular direction, and alternating with untransparent fibres. On the addition of acetic acid, the whole becomes very transparent, and the parallel bundles of tendons (fig. 121, 1), are now scarcely visible; they are much broader than before acetic acid was added. A great number of elastic fibres are visible, either bent vermicularly or almost straight, at tolerably regular distances from each other (fig. 122, 2).

The transverse section, when treated with potash, shows distinctly a division of the secondary bundles into smaller ones; each of the former consisting of six to eight primary bundles. The latter are united together by a shapeless ligamentary substance, of which a thicker layer is found between the compound bundles just mentioned. The kernel fibres become at the same time very distinct—being the only part that remains after a protracted action of potash and addition of water.

The swelling, which the transverse sections undergo by the action of acetic acid, and the subsequent swelling of the fibres, especially in breadth, has the effect of turning the terminal parts and forming swollen bundles, of which the breadth is equal to the thickness of the swollen object. The elastic fibres are placed at right angles to the length of these bundles (fig. 122). The bundles represented by a thinner transverse section, are themselves thinner also (fig. 123). Now, as these bundles present nothing except parallel elastic fibres, similar to what are seen on the longitudinal section (fig. 121, 2), and neither transverse bundles, nor threads, nor lines, it follows that the primary bundles of tendons are neither enclosed in tubes nor divided into groups, but are so much squeezed together in consequence of their swelling in acetic acid, that they seem to form one single mass. It would appear, however, that the fibres have a more firm connection in one place than in another, because a number of these bundles become detached in mass.

It follows, therefore, from this observation, that the larger and smaller bundles of tendons are not surrounded by membranaceous integuments of a peculiar composition, but, probably, by a layer of the same gelatiniferous matter which constitutes the primary threads of the tendons, and that, therefore, the secondary bundles of tendons consist only of gelatiniferous tissue, excluding the

fibres which are so intimately interwoven with the gelatinous fibres, are formed from the cell-kernels, and that a bundle of ligamentary tissue is produced from the imperfectly developed cell to which that kernel belongs. This view, if really in accordance with nature, would beautifully illustrate the close connection existing between threads of gelatinous and elastic tissues. I have, however, not made any observations myself on this point.

The ligamentary tissue is stated to hold the lowest rank among the vascular tissues, because it is the one that takes the smallest share in the animal functions; but on the other hand, it is quickly re-produced when deprived of part of its substance. Such a rapid re-production in a diseased state indicates a great activity in its healthy condition; and this reproduction takes place much more rapidly than is usually supposed. It even takes the place of several other tissues that

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threads of elastic tissue which they contain. In the cellular tissue, however, by which the secondary bundles are united together, there exist in addition blood-vessels and fat-tissue.

The fibres of a fresh tendon are often regularly wrinkled (fig. 124), and are in all other respects similar to those of loose cellular tissue.

In examining the fibres of the tissue of the tendons a solution of corrosive sublimate and tannic acid are especially fitted to make them distinctly visible. Alcohol will serve the same purpose.

Fibres of the tissue of tendons, when swollen by acetic acid, return to their former shape, after the acid has been neutralised with ammonia.

Ligamentum sacro-tuberosum,—a ligament consisting of real ligamentary tissue, according to the opinion of the present time,—after having been kept for fifty hours in a strong solution of potash, has become a shapeless tissue. The slender threads protruding from various spots, have the appearance of a pearl necklace, consisting of little globules placed at certain regular distances (fig. 125). The potash, therefore, has acted differently upon different parts of the thread, in consequence of which some parts are dissolved with ease, and others, placed alternately between the former, with much more difficulty. On the addition of water, the greater part of these fibres disappear, and the little bodies which have assumed the appearance of globules, remain loose and irregularly mixed. The subsequent addition of strong acetic acid makes the whole shrink, which is a proof that some fibres are still left concealed.

It would appear, therefore, that there are two different substances contained in this ligament, and hence it deserves a closer investigation. (Donders and Mulder.)

may have disappeared, and is, therefore, much more rapidly reproduced than these. With these reproductions, however, are not to be confounded the pseudo-membranes of the serous membranes, which appear to consist of bi-oxide of protein, at least until they have reached a certain stage of development.*

We have already mentioned that the gelatinous tissue is not a primary one. The skin of a fœtus does not yield gelatine. Even after a boiling of twenty-four hours, its fibres are not yet dissolved; that which is dissolved is called *pyine*, and its properties are the same as those of tri-oxide of protein, the same substance which exists in pus;†—the undissolved part is probably elastic tissue. In the bony tissue it is first chondrin, and subsequently it becomes gelatinous tissue. (See *Bony Tissue.*)

It would appear, therefore, that the substance from which the ligamentary tissue in the fœtus is produced, is oxide of protein, and it is likely that such a process takes place throughout lifetime, in the reproduction of the absorbed ligamentary tissue. The manner, however, in which this is effected is not known, for no connection has yet been found to exist between oxide of protein and gelatine,‡ unless we should merely add nitrogen to the elements of the tri-oxide of protein and subtract the elements of water, or indicate this connection in some other arbitrary manner. We must especially bear in mind that we have not yet been able to prepare gelatine from protein, and until this has been performed, we are unacquainted with the nature of this conversion. We are, therefore, yet in the dark both regarding the formation of gelatiniferous substances, and consequently also of all the tissues produced from these substances, and regarding

* Scheikundige Onderzoekingen. Deel I. p. 557.

† See Von Bibra, Chem. Unters. verschiedener Eiterarten. Berlin, 1842, S. 14 and 230, and Bulletin 1839, p. 406, and Scheik. Onderz. Deel I. p. 572.

‡

		Tri-oxide of protein.		Gelatine.	
	C	40	51.45	13	50.37
	H	32	6.72	10	6.33
	N	5	14.90	2	17.95
	O	16	26.93	5	25.35

the cytoblastema or the cell-forming substance, of which ligamentary tissue is produced.

We ought to pay particular attention to the presence of a greater or smaller quantity of elastic tissue in all gelatiniferous tissue, not only with reference to the nature and structure, but also to the origin of both. This intimate intertexture of threads of ligamentary and elastic tissues, this circumvolution of threads of the latter around those of the former tissue, indicates that they are both of the same origin. In chemical properties, however, they are essentially different. We shall see hereafter that the formula for elastic tissue is $C^{52} H^{40} N^7 O^{14}$, that for gelatiniferous tissue being either $C^{13} H^{10} N^2 O^5$, or a polymeric of this, and, therefore, entirely different from the former.

We have already (p. 531) drawn attention to this intimate connection between threads of ligamentary and elastic tissue. The difference in their chemical composition shows, that they are not of the same origin. If Henle's view be the correct one, viz., that the thread of gelatiniferous tissue is formed from the imperfect cell-wall, and the thread of elastic tissue from the kernel of this imperfect cell,—it is evident that the formation of the one must aid or promote that of the other. The chemical transformation of matter,—for instance that proceeding from the kernel,—whilst giving rise to the production of a thread of elastic tissue, must assist in the formation of threads of gelatinous tissue, for these two formations take place in the immediate neighbourhood of each other, indeed, in the same little elementary organ, and their results are products of a different chemical character.

Any attempt, however, at present, to explain the formation of these two tissues from the nourishing liquid, will be fruitless.

If we may assume as proved, that the ligamentary tissue is not a primary but a secondary tissue, then it is equally proved, that gelatine cannot *serve to form cells and membranes*, as Liebig thinks.* First, we do not know, in the whole

* Thier-Chemie, 2 Aufl. S. 89 and 90.

organism, one single cell consisting of ligamentary tissue, and as the membranes are secondary products, they cannot possibly originate directly from gelatine, which, when consumed, must serve to produce something else; for it is not again found unchanged either in the fæces or in the urine.

The connection which we have indicated (p. 325) between the two extractive matters produced from protein by the action of alkalies and gelatine, throws some light upon the manner in which the latter may be formed. Gelatine will certainly not produce any organ directly, but only when it is in the nascent state. If gelatine, after being taken as food, could really be converted into cells, it ought to be considered as one of the most important nutriments, for cells constitute the chief part of the original solid substances of the body. There is no ground, however, for supposing that it acts as a nutriment in this way. But its presence in the blood,—conveyed thither, for instance, in the form of soup,—renders the reproduction of the gelatinous tissue in the organism superfluous, or, at least, less necessary, and the quantity of ligamentary tissue reproduced is therefore in an inverse ratio to the quantity of gelatinous tissue supplied as food in a state of solution.

Although, therefore, gelatine cannot be directly employed for the formation of cells, it is, nevertheless, to be called nutritive matter, because cells originate from it. For this reason it promotes indirectly the reproduction of ligamentary tissue in the case of emaciation; and in bodily exertion, the use of gelatine in addition to other food does actually render nutrition better and more effectual, because its presence in the blood makes the reproduction of this ligamentary tissue much less necessary. In this case also it may be said to render an *indirect* service. (See *Food*.)

There exists a great number of laminar integuments, produced from ligamentary tissue, having the name of serous membranes, which, when in a normal condition, secrete a liquid, that may accumulate in case of illness. It occurs in dropsy of the abdomen, the chest, and the brain. This liquid varies in composition according to the nature of the mem-

branes by which it is secreted. Its composition is known only as it exists when accumulated in a state of disease. I give here one instance of its composition.

Water from the brain, according to Berzelius :—

Albumen, ...	1.66
Matter soluble in alcohol and lactate of soda,	2.32
Chlorides of sodium and potassium, ...	7.09
Soda, ...	0.28
Organic matter, insoluble in alcohol, ...	0.26
Earthy phosphates, ...	0.09
Water, ...	988.30

I myself have obtained similar results (Berzelius, Bd. 9, S. 198). The proportion of albumen in this liquid is occasionally much larger; sometimes it is even nearly equal to that of the serum of the blood. Marchand found urea in the serum of the cavity of the abdomen.

We may therefore consider this serum as a kind of diluted blood serum. Especially as regards the proportions of salts they contain, the two closely resemble each other; the quantity of albumen alone is generally smaller than in the serum of the blood. It is not known what causes the retention of this albumen, when the watery liquid is separated from the serum of the blood by perspiration; but it is a fact that deserves to be noticed.

In every case the secretion of this serum in a state of disease is nothing else than a mere transmission of nutritive liquid. It is not likely, however, that in a healthy state its composition will be the same as when accumulated in disease. Probably it will then be more concentrated; but its composition is not known.

The serous membranes are covered, besides, with a simple laminar epithelium, of which we have treated before, p. 497. In case of inflammation, the latter is soon removed, and this fact affords a sufficient explanation, why a larger quantity of liquid, differing in composition from ordinary serum, is then perspired.

II. Elastic Tissue.

What is called in the animal organism elastic tissue, is a thread-like tissue of a very elastic nature, and very generally diffused through the body. It exists either in an almost pure state, or mixed with ligamentary tissue or other elementary forms. It consists either of simple threads, like those in the inferior vocal ligament (fig. 132); or of threads with projecting and curling ramifications; as found, for instance, in the yellow ligaments of the vertebræ (fig. 131); or of threads with ramifications, which are gradually united again into one, and present themselves as a very dense vascular net with anastomoses, as in the elastic tunic of the arteries; or finally, the diffusion and combinations of the threads become so numerous, that they constitute, as it were, a thin membrane, fully deserving the name of elastic membrane, as in the intermediate tunics of the arteries and veins (see below).

The ramifying threads occur in especial abundance in the organism, and form a really important constituent of it.*

* A longitudinal section of the *cervical ligament* of a cow exhibits parallel fibres, which are scarcely detached from each other under the action of acetic acid (fig. 126). The fibres themselves are often rough, owing to a little adherent ligamentary matter (fig. 127), which is dissolved by potash. This property renders it easy to separate them from each other (fig. 128).

When kept in potash for twenty-four hours, there appear very distinct and elastic fibres, a little thinner than in the natural condition, which easily separate from each other and exhibit some ramifications (fig. 128).

The transverse section presents either circular, more or less elliptic, or angular sections of the elastic fibres of different size, placed very close to one another, with very little intermediate matter, and hardly giving way on the action of acetic acid (fig. 129).

After the cervical ligament has been kept in potash ley for a great number of days, it presents itself to the naked eye as a gelatinous substance, which is quite transparent, with the exception of a few thick white bundles. Under the microscope this gelatinous substance appears as one mass of little globules. In the white bundles, however, a great number of elastic fibres are visible, which are all sharp pointed (fig. 130), and besides these fibres, there are large, round lumps, consisting of a granular substance. This granular substance is insoluble in water.

When the cervical ligament is kept for six months in a saturated solution of potash, diluted with four parts of water, a part is left undissolved, which,

The proportion of threads of elastic tissue that is mixed up with other elementary forms, is very variable. In the ligamentary tissue, for instance, where it is nowhere wanting, not even in that by which the primary bundles of nerves are united together, it sometimes accumulates to such an extent, that it constitutes about the half of the whole mass. This is the case, for instance, in the fascia lata of the thigh, which may indiscriminately be said to consist either of elastic or of ligamentary tissue.

There are some tissues which consist almost entirely of elastic tissue, but nevertheless differ from each other. The cause of these differences is the intermixture of a small portion of other elementary forms, especially of threads of ligamentary tissue, which are converted into gelatine by boiling.

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under the microscope, presents the appearance of little pointed fibres of elastic tissue.

When kept for six months in strong sulphuric acid, it is dissolved, and the solution has a brown colour.

In strong nitric acid it is left partly undissolved.

In acetic acid it has undergone no change.

In hydro-chloric acid it is dissolved, giving a brown solution.

The yellow ligament of a young man of 21 *years old.* A section, taken parallel to the surface, exhibits a net of intermixed, ramifying, flat threads of elastic tissue, interwoven with a little cellular tissue. On the addition of acetic acid, the threads of elastic tissue remain unchanged, and constitute a net of coherent threads, having a transparent substance between them (fig. 131, *a*).

When cut on the transverse side downwards, the fibres become detached from one another, and there appears a transparent, swollen, intermediate substance placed between the fibres. This is ligamentary tissue, swollen by the action of the acetic acid, having no distinct form, and filling the interstices between the fibres of elastic tissue. When potash is added, these fibres again contract, and therefore the intermediate matter resembles ligamentary tissue.

After having been kept in a strong solution of potash for 48 hours, no change has taken place. When water is added, the elastic fibres give way by the swelling of the ligamentary tissue between them; some fibres are even entirely isolated. The remaining fibres have retained their elasticity, notwithstanding the action of the potash. On the potash being neutralised by acetic acid, and tincture of iodine added, the elastic fibres become very dark coloured.

A transverse section (fig. 131, *b*), treated with acetic acid. The elastic fibres, of which the sections are more or less elliptic or angular, are separated very much from each other by the action of acetic acid, and when ammonia is added, they contract again (Donders and Mulder).

Elastic tissue, wherever it exists,—either in the yellow ligaments, in the cervical ligament, or in other organs, has always the same chemical character. The observations of Eulenberg upon the gelatinising property of the cervical ligament, and those of Valentin, upon the solubility of the elastic tissue of the interior layer of the thoracic membrane, are obviously attributable to a confusion of threads with ligamentary tissue. The elastic tissue has further claims to our attention, if we bear in mind, that it consists of what Henle calls kernel-fibres, and that there is some ground to class the kernels, which are seen in so many elementary forms, with elastic tissue; for those kernels are in many respects similar to elastic tissue (see pp. 491 and 492).

The general properties of elastic tissue are the following. When boiled in water it produces no glue. The threads appear unchanged, even after they have been boiled for 40 hours. It resists for a very long time the action of strong boiling acetic acid, but in the end,—that is, after it has been boiled for a number of days,—it is gradually dissolved. It is unchangeable by strong acetic acid at the ordinary temperature. It is dissolved by digestion in hydrochloric acid, diluted with a little water. When the solution is neutralised with ammonia, an organic substance is precipitated, which is soluble in alcohol and water. Pure elastic tissue is decomposed by nitric acid, without the formation of xantho-proteïc acid. When treated with a potash ley of moderate strength, it is at last, but not until after a great number of days, completely dissolved and converted into a transparent jelly. This property of elastic tissue, of being very sparingly soluble in strong acetic acid and potash, affords an opportunity of obtaining it easily in a pure state.

In the cervical ligament of cows it is found in large quantity, being here only intertwined with a few threads of ligamentary tissue and saturated with nutritive fluid.

When such a ligament is dried and grated, and then treated with potash, acetic acid, water, alcohol, and ether, elastic tissue may be procured in a purer state than any other elementary form can be obtained.

According to the analyses of J. W. R. Tilanus, the composition of pure elastic tissue may be represented by the formula $C^{52} H^{40} N^7 O^{14}$. This composition has not only been derived from analyses of the pure tissue, but has been further confirmed by a combination of elastic tissue with chlorine, which may be expressed by the formula—

$$C^{52} H^{40} N^7 O^{14} Cl^*$$

There appears to exist some relation between gelatinous and elastic tissue, which deserves to be noticed. In one of the combinations of gelatinous tissue with chlorous acid, the latter is united with four of gelatine.

$$4 \times (C^{13} H^{10} N^2 O^5) = C^{52} H^{40} N^8 O^{20},$$

a formula which also represents the composition of the hydrate of gelatine, viz., the substance which is obtained by boiling gelatine for a very long time in water. The formula for elastic tissue, $C^{52} H^{40} N^7 O^{14}$, therefore, differs from four equivalents of gelatine by containing one equivalent of nitro-

* Elastic tissue of the cervical ligament, treated only with cold water, alcohol, and ether.

C	54.90	54.39
H	7.25	7.28
N	17.52	17.30
O	19.97	20.72
S	0.36	0.31

This still contains some ligamentary tissue.

Treated with acetic acid, water, alcohol, and ether.

	Found.	Atoms.	Calculated.
C	55.65	52	55.88
H	7.41	40	7.02
N	17-74	7	17.42
O	19.20	14	19.68

The combination with chlorine yielded on analysis—

	Found.	Atoms.	Calculated.
C	51.55	52	52.43
H	6.64	40	6.62
N	15.94	7	16.67
O	19.93	14	18.43
Cl	5.94	1	5.85

This is, however, not the only combination with chlorine that may be obtained. See Scheikundige Onderzoekingen, Deel III.

gen and six equivalents of oxygen, ($N O^6$,) less. It is, therefore, beyond doubt that there is some relation between gelatinous and elastic tissue; but at present we can merely indicate its existence (see p. 538).

The following parts of the animal body are now classed under the head of elastic tissue, though they contain—the cervical ligament of cows probably least of all—a greater or less quantity of threads of ligamentary tissue. The parts are, the yellow ligaments of the vertebral column; the ligaments by which the cartilages of the larynx, the wind-pipe, and the bronchiæ are united together and fixed to the tongue-bone (os hyoïdes); the elastic tunic of the arteries and veins; the other tunics of the arteries and veins, all of which are more or less intermixed with ligamentary tissue (those that are circular and have involuntary muscular fibres); the exterior layer of fibres of the œsophagus, by which this is united with the larynx and the wind-pipe. The serous membranes, more especially the peritoneum, have on many places a layer of elastic tissue, which unites the membrane with the parts below.

Such layers are found also between the peritoneum and the ensiform cartilage, between the peritoneum and the bladder; they are thinner on the intestines, and wholly wanting upon the kidneys and the liver. They are also found below the pleura on the side of the breast, but neither upon the lungs nor upon the heart. The skin, also, is interwoven with elastic fibres. Finally, elastic fibres exist between the cartilaginous bodies of the elastic cartilaginous tissue.

It appears from all this, that there is a close connection between the origin of the elastic and that of the ligamentary tissue.

KK. Cartilaginous Tissue.

What are called cartilages are solid, flexible, and more or less elastic parts of the organism, containing only a small portion of inorganic substances, and having either a cellular or a fibrous structure. They may be divided into two classes, ac-

cording as the cells are situated in a base devoid of structure, or are inclosed by fibres. The former are white, more or less bluish, the latter yellowish. Cartilages, of which the cells are found in a shapeless base, are called *true* cartilages; but when the base consists of fibres, they bear the name of *fibrous* cartilages. The latter, however, ought to be subdivided into two kinds. That which possesses elastic fibres, we shall call *elastic cartilage;* and by the name of *fibre cartilage* we shall indicate that kind in which the nature of the chief mass of the fibres is different from that of elastic tissue.

To the class of true cartilages belong the cartilages of the ribs, the ensiform cartilage of the sternum, the cartilages covering the joints, those of the nose, and almost all such as form part of the apparatus for respiration. Under the head of elastic cartilage may be classed the epiglottis, the cartilages of the ear, and the cartilages covering the infra-maxillary joint. To the fibrous kind belong the synchondroses, the intervertebral cartilages, and different cartilages between the joints.

The true cartilages consist of a shapeless or finely granular substance, having cavities of considerable size (fig. 133 and 134), which are filled with a transparent mass, in which are found little vesicles, containing in some places one or two kernels. If the cavities just mentioned are considered as cells, the latter constitute a complete type of an endogenous cell-formation. Of such cells, four are sometimes seen pressed together, and lying next each other regularly; sometimes two or three belong to one cavity. The kernel of the cells has all sorts of forms, and is sometimes devoid of the little kernels or nucleoli; in some cases the kernels of the cells are absent, and replaced by fat-cells.

At the surface of these true cartilages the before-mentioned cavities lie pressed closely upon each other (fig. 133), and here they exist in much larger quantity than at a distance from the surface (fig. 134).

These cartilages consist, in great part, of matter yielding chondrin, for which the formula

$$10\,(C^{32}\,H^{26}\,N^{4}\,O^{14})\,S$$

has been established (p. 328). Their composition, when analysed as they occur, is similar to that of the chondrin which is obtained from them by a protracted boiling of several hours (p. 328), but their composition cannot possibly be quite the same as that of chondrin; for during the boiling the kernels are dissolved much more slowly, leaving the liquid turbid, and on filtering it, the liquid that runs through is quite transparent.

It is impossible, therefore, that the whole of the cartilage should have exactly the same composition as the chondrin, which is obtained from it by boiling; and the fact, that the same results have been obtained from the analysis of rib-cartilage as from that of their product, chondrin (see p. 329), may again serve to show the limits of the accuracy of elementary analysis.

As to chondrin itself, I consider it a chemical body of a peculiar nature, in so far as it is procured by dissolution of the granular base alone; and as it is this granular substance which is dissolved first when cartilage is boiled, the first decoction may probably yield chondrin chemically pure. By protracted boiling the cell-walls are also dissolved, and the solution, so obtained, must necessarily contain other substances besides. It would be strange, indeed, if this granular base, the cell-wall and the contents of the cells of the cartilages, should all have exactly the same composition.*

When cartilages are boiled, the inter-cellular substance is the first that disappears, whether it be fibrous or not. Subsequently, kernels are seen floating through the liquid, some of which are still enveloped in cells. The whole of the granular part remains long unaltered. Rib-cartilage, of which the inter-cellular substance was chiefly fibrous, was boiled for forty-eight hours, the liquid repeatedly decanted, being every time allowed first to subside (as it would not pass clear through the filter), and then evaporated and digested with ether and alcohol. A small portion of this liquid was filtered twice, and yet there were, and remained in it, kernels and granules, and

* Several reagents—for instance, the bi-chloride of platinum—precipitate only part of the substance; sufficient means are at our command, therefore, to attempt a separation of these substances.

even a few cells, visible under the microscope. Of chondrin, thus obtained, the carbon and hydrogen were determined, and the result agreed completely with the formula. The same proportions of carbon and hydrogen were obtained by an ultimate analysis of cartilage. I am inclined to suppose that the chondrin that has hitherto been analysed, has always contained microscopic molecules.

Part of what remained undissolved, after a boiling of forty-eight hours, was boiled once more for an equal period, and during this process it became almost completely invisible to the naked eye. But by the aid of the microscope, we observed a large number of exceedingly minute granules, granular kernels, and granular cells, in an almost unchanged condition. These, therefore, appear completely to resist the action of boiling.

We saw, besides, small fragments, visible to the naked eye, exhibiting a base devoid of any structure, and containing a great number of granular kernels. This liquid is also distinctly affected by all the reagents that act upon chondrin. (Donders.)

Even when filtered clear, chondrin holds a large quantity of salts of lime and other bases in solution, amounting together to 3.5 per cent.

It is likely that these cartilages are formed from tri-oxide of protein, and therefore subsist directly upon the constituents of the blood. (See p. 314.)

Some of these true cartilages may, in the course of life, be either wholly or in part converted into fibrous cartilage. In this case they then generally present in their interior certain very brilliant lines (fig. 136, 1), which, when examined by the microscope, appear to consist of straight or gently curved fibres, running parallel with each other, and extending themselves into the rib-cartilage in the direction of their diameter (fig. 134, 4). Two other changes take place in connection with the above: first, the cell-kernels disappear, and are replaced by the fat-cells before mentioned (fig. 135, *c*); secondly, these cartilages, which become fibrous, are the very same that at a later period undergo ossification.

Although it is said that these cartilages are devoid of blood-vessels, yet Dr. Donders has often shown me distinct blood-vessels in rib-cartilages, obtained from persons not older than thirty years.

Regarding the true cartilages,* I communicate the under-

* *Rib-cartilage* from a young person of 22 years old.

The main bulk consists of a finely granular, occasionally fibrous basis with little bodies of a very transparent substance. The latter are very different in form, according as the part observed is situated towards the outside or more in the axis of the cartilage. Those situated more in the interior are roundish, sometimes triangular, two succeeding ones being turned with their planes towards each other (fig. 133, 1). Those towards the outside are much more elongated (fig. 135, *a*), and neither triangular nor roundish; they are arranged in longitudinal series (fig. 133, 2). Those towards the centre are larger, and placed irregularly, in most cases, at greater distances from each other (fig. 134). Towards the outside, they become smaller and more numerous.

In these little bodies we find sometimes one, but more frequently several cells (1), having either a roundish, angular, or oblong form, and a somewhat darker appearance than the other parts of the little body, which in its turn may be distinguished by its lighter colour from the granular base, in which it is situated.

These oblong bodies usually contain two or four cells, placed in one row (2). In those of a more roundish form, the cells are arranged in different directions, their broad bases being turned towards each other (fig. 135, *C*).

Besides cells, these cartilaginous bodies contain fine granules, a few kernels (*b*, 1), and globules of fat (*c*, 1).

In almost every cell of the peculiar cartilage here mentioned, a single globule of fat, of a larger size, may be seen (*c*, 2), and in some cases several others of a smaller size. Towards the central part of the cartilage, these globules are largest and most numerous.

The middle part of the cartilage is occupied by the cells, and these cells are surrounded by a white rim, which presents nothing peculiar, and is in direct contact with the other granular or fibrous mass of the cartilaginous tissue.

Near the surface of the cartilage, the basis between the cartilage bodies has scarcely any distinct structure (fig. 133); a little further from the surface, it assumes a finely granular appearance, and becomes less transparent (fig. 134, 3), and in some places fibrous (4). Here and there globules of fat are lying in the intermediate substance (5).

If we take a transverse section of the rib-cartilages of full grown individuals, we perceive in most cases a more or less complete concentric line, at about 1-12th of an inch from the surface. It resembles substance in appearance, is very soft, and when pressed it yields a liquid substance (fig. 136, 1). When examined under the microscope, this substance appears to consist of fine fibres, in most cases arranged parallel to each other, between which there appear only a few cartilage bodies, of a large size, in most cases of an oblong

mentioned observations, from which I draw the conclusion,—that the substances which must be distinguished in them are at least four in number, besides fat-cells and vessels. These are, cell-walls, which dissolve but slowly in potash and sul-

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form, and containing a great number of cells. These fibres run in the direction of the diameter of the cartilage, and are in most cases either straight or slightly curved (fig. 134, *a*).

The part within this concentric line or circle contains many more cells than that which is outside, is often filled with a great number of large globules of fat, and in several places the base is formed like a laminar mass; resembling, in some degree, the plates of the bony tissue. In this mass the outlines of the cartilage bodies are much less distinct than elsewhere. In some parts of this laminar mass the cartilage bodies with cells are not distinctly seen.

A longitudinal section of the external plane, taken at right angles to the surface, exhibits cartilage bodies, most frequently of an oblong form, lying in the granular mass. In a section taken parallel to the surface, these bodies are roundish. They therefore appear to have the form of discs, placed parallel to the surface of the cartilage, appearing narrow in two directions, and roundish in the third.

When a longitudinal section of the concentric fibrous part, just mentioned, is examined, it will be seen that this circular part appears as a continuous canal, which is therefore a circular canal, constituting a line of demarcation between the parts within and those without the circle.

In the part within the fibrous and much more loosely-formed circle, the same laminar structure, mentioned before, is found also on a longitudinal section. The form of the cells and everything else is not different from what has already been stated.

When the cartilage is digested in ether, the globules of fat disappear, and are replaced by membranaceous bags, which have shrunk together (they are called the membranes of the fat cells). (Fig. 135, *d*, 1). All the rest has remained unaltered.

When treated with a strong potash ley, the fundamental layer is, in a few hours, converted into a homogeneous, shapeless substance, in which nothing can be distinguished; whilst the cartilage bodies become loose and isolated, and are much later of being dissolved.

In the rib-cartilage, therefore, we find *fibres*, a *finely granular substance, cells with kernels and globules of fat*, which are altogether imbedded *in a solid transparent substance*. We have here, therefore, six different substances, which may be all of a different chemical character. We have not arrived at perfect certainty as to the laminated part.

The *thyreoid, cricoid*, and the *azytænoid cartilage* of the larynx, present exactly the same properties as that of the ribs.

After having been kept in a strong solution of potash for four hours (being previously extracted with ether), the cartilage bodies, with their clear, transparent edges, have become invisible; but now the little cells within these

phuric acid; cell-kernels, which resist for a long time the action of every solvent; the substance of which the cartilage bodies themselves consist, which is likewise but sparingly soluble; and finally, the basis or fundamental substance,

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bodies are very distinctly visible; the globules of fat have disappeared through the action of the ether, and in their stead the whole cell is filled with granular substances, the remains of the cell-membranes of the empty fat cells. The fundamental layer of the tissue has assumed a more laminar appearance, but not even a trace of it is yet dissolved. On the addition of water the cells become totally invisible, and the whole is changed into a granular, shapeless mass. When more water is added, this mass disappears, and is suddenly dissolved, whilst the cartilage bodies float insulated in the liquid, presenting very distinctly their cells, with the kernels and the membranes of the fat-cells.

Though, therefore, the fundamental layer were a simple body,—a supposition, however, which seems to be disproved by its structure,—the rib-cartilages are nevertheless not formed of one homogeneous substance, because it is apparent that a difference of solubility in the same liquid exists between the fundamental layer and the cartilage bodies.

The same effect is produced by strong sulphuric acid, in which liquid the cartilage bodies are even found freely floating (fig. 137). After a period of seventy-two hours, all the bodies, and even all the cells, have disappeared; and almost everything is dissolved in the acid, except a few finely granular bodies, which are seen floating in it.

The monohydrate of sulphuric acid renders rib-cartilage brown. When thin plates of the latter are allowed to remain in it for twenty-four hours, they swell and become gelatinous. When placed under the microscope, nothing can be distinctly seen. On the addition of water, the fundamental layer outside the little objects is dissolved, and the cartilage bodies, or rather the cells contained in them, float freely in the liquid. When left in the acid a little longer, the transparent edges of these bodies become entirely invisible, and the cells with their kernels are apparently the only parts remaining. We find, therefore, the following order in the degree of solubility: the fundamental layer, the transparent edge of the cartilage bodies, and the cells, the latter offering the longest resistance. When left in the acid still longer, the cells also disappear, leaving behind nothing but fine, granular bodies, which were formerly contained in them.

Strong sulphuric acid, therefore, affords a very fit means for studying the nature of the true cartilage, and discovering chemical differences in the substances which it contains. The fibres mentioned above offer a little more resistance than the purely granular fundamental layer; they swell and become much thicker. In point of solubility in strong sulphuric acid, therefore, subsequently diluted with water, these fibres hold an intermediate place between the granular fundamental layer and the transparent parts of the cartilage bodies.

which is placed between these peculiar bodies, being partly granular and partly fibrous, and easily soluble both in potash and sulphuric acid.

In a chemical point of view, therefore, true cartilage requires a new examination.

The fibrous cartilages are parts of the organism which are of a very elastic nature. Generally speaking, the fibres, of which the main bulk of these cartilages consists, are thick and rough on the surface, and run almost parallel with one another. Between these fibres only a few cells and sometimes merely kernels are interposed. Each cell contains one or more of these kernels.

It is impossible that the chemical composition of these cartilages should be a simple one. Those that contain cells, appear to yield chondrin when boiled; the reactions, at

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After having been kept in very strong acetic acid for five hours, the transparent edges of the cartilage bodies have disappeared, but the cells that are within them and their kernels have become very distinctly visible. The finely granular fundamental layer is also very visible, and the fibres mentioned above are likewise very distinct and dark in appearance.

Fragments that have previously been treated with ether exhibit the same phenomena in every respect; but they present this peculiarity, that the membranes of the fat-cells, within the cells, which after the action of the ether have collapsed, again swell and become globular by that of acetic acid.

After an action of five hours, therefore, acetic acid dissolves nothing of the true cartilaginous tissue.

It follows from what has been stated—

1st, That true cartilaginous tissue contains no elastic tissue; for the fibres before-mentioned, being so readily soluble in potash, are totally different from those of elastic tissue.

2d, Besides fat and fat-cells, kernels, and the further contents of cells, they also contain cell-walls, which are but slowly dissolved by potash and sulphuric acid.

3d, The substance, of which the walls of the cartilage bodies consist, is different from the tissue in which they are placed,—being less soluble in strong potash-ley and sulphuric acid.

4th, The substance, which constitutes the basis of this cartilaginous tissue, is partly granular, partly fibrous, and easily soluble in potash and sulphuric acid.

As regards the chondrin, if this is obtained by boiling the cartilages into a pulp, it cannot be anything else than a mixture of different substances. On a future occasion, we shall revert to this point. (Donders and Mulder.)

least, which are mentioned as being peculiar to them, are the same as those of chondrin.*

* *Intervertebral cartilages of the vertebræ of the loins of a man 23 years old,* taken about the circumference, parallel to the broad surface. The fundamental layer or basis consists of fibres, situated in various groups close to one another. In some places nothing more can be distinguished than a group of a granular substance. The fibres are placed either parallel in bundles or scattered in every direction, being here and there intermixed with cells, which are generally arranged in rows, different in size, most frequently containing a kernel, and being sometimes simply cell kernels surrounded by a clear, transparent rim (fig. 138, *a*.) A great difference exists between different portions of the same tissue, one of the causes of which is, that the fibres running in two directions which cross each other, have been intercepted in different ways. The direction in which the fibres cross each other is from above downwards, making a certain angle with the vertical line. Sometimes, however, a large number of fibres is aggregated, as it were, into one spot; sometimes they are fewer in number, and then the cells have the superiority. In some places the fibres form wide meshes, enclosed by curved lines; in these meshes no elementary forms can be properly distinguished.

When taken from the exterior, parallel to the circumference, the fibres present themselves running in very regularly parallel undulated lines, and united into bundles. They possess only very few cells or kernels; but between the fibres a great number of little dark-coloured bodies are seen, resembling kernel fibres.

When taken from the middle of the intervertebral cartilage (fig. 138, *b*), which is soft and tender, the part immersed in water presents a faintly fibrous structure, imbedded in a granular mass, and very distinct cells swelling in the water, some of which contain three, others two kernels, but the greater part only one that is duly defined.

This cartilage becomes more fibrous the nearer we approach to the solid portion of it.

The soft part is but little changed by acetic acid, only the cell-kernels become more distinctly visible. After the tissue has been in acetic acid for four hours, it is but slightly altered.

A small fragment, which was taken from the circumference of the cartilage, was kept in a strong solution of potash for fifty hours, and had then lost all definite form. On water being added, the whole was dissolved, with the exception of the cells with their kernels and a single group of fine, elastic fibres, (derived from the ligamentary tissues by which the several parts of the elastic tissue are held together?) If the water be allowed to act still longer, the cells disappear likewise, but in most cases the kernels remain.

A piece from the middle, or soft portion, which had been kept in potash for fifty hours, presented no distinct form or structure. When water is added, the whole is very rapidly dissolved, with the exception of a few cell kernels.

The fibres of a piece, taken from the circumference, and placed in strong acetic acid, do not swell so instantaneously as those of the ligamentary tissue.

The cartilage between the joints of the knee, from which Müller obtained gelatine by boiling, consists of ligamentary tissue intermixed with kernels, and does not belong to the fibrous cartilages, as he supposed. It is a little

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The fibres retain their distinct appearance, whilst the cells and their kernels are rendered even more distinct.

A fragment, taken from the exterior of the intervertebral cartilages of the vertebræ of the loins of a young man 22 years old, presents a great number of strong, very distinct, more or less curved fibres, running parallel to each other, but in which nothing else can be sufficiently distinguished. At small regular distances, these fibres are mixed with much less transparent portions.

After having been kept in a strong potash solution for four hours, the fibres, although less distinctly seen, are still perceptible. When water is added they suddenly become invisible, as if they were dissolved. They become, however, gelatinous only for a time, and this is the cause of their disappearance, for after a few moments, when the water has acted more thoroughly, the fibres become much more visible again; but they appear thicker, broader, and more transparent than previous to the action of the potash, and at small distances they unite together in oblique directions.

When kept in strong sulphuric acid for four hours, it becomes more or less brownish, and the fibres swell and become gelatinous. The fibres have the appearance of being collected into sharply defined bundles. When water is added the whole becomes whitish and less transparent under the microscope, but the fibres that were visible at first do not reappear in a distinct form. In some places in the direction of the fibres which have disappeared, dark bodies are perceptible, which could be distinguished even before the fibres were acted upon by the acid, and which resemble the kernels of the primary bundles of the muscles.

When kept for five hours in strong acetic acid, the effect is in so far the same as that produced by sulphuric acid, that the fibres, although they have not disappeared completely, are yet less visible, and the bundles very distinctly brought out; they are thick bundles formed from the original fibres, which have become more or less swollen. In some places there appear isolated portions of fibres, running in an undulating direction, and resembling kernel-fibres.

On other places these bundles are wanting, and the fibrous form is predominant.

Water produces no change in their appearance.

Between these bundles whole rows of cells are found, which are placed in the same direction as the bundles.

It follows from these reactions, that there is not the slightest connection between elastic cartilages and these intervertebral cartilages, but that on the contrary the latter represent a peculiar tissue, united into bundles and of a fibrous structure; that this fibrous part is rendered gelatinous by strong sulphuric acid and not restored to its former appearance by the addition of water, whilst those parts, by which the bundles are separated from one another,

more opaque than ligamentary tissue, and it is not rendered so transparent as the latter when treated with acetic acid. Its chief characteristics, however, are the same as those of the latter, and differ considerably from those of the inter-

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remain altogether unaltered; further, that they contain fibres of a different kind, resisting the action of strong sulphuric acid, and resembling kernel fibres; and finally, cartilage cells, with perhaps a few threads of ligamentary tissue. (Donders and Mulder.)

I have received from Dr. Donders the following additional information regarding the fibrous-cartilages.

I have not examined them in their very first stage of production. At the period of birth only the external part is somewhat solid and hard; two-thirds within are still soft, and have very much the same appearance as the vitreous fluid of the eye.

I consider myself justified in assuming, that I here pass under review the subsequent periods of development of this tissue, by commencing with the entirely soft interior part, and proceeding to the hard exterior.

The interior part, which is still in an entirely liquid state, presents irregular groups, which seem to consist of irregular cells.

As soon as water is added, it is absorbed by the cells, and they appear with a completely globular form, placed in juxtaposition (fig. 139). Between these groups of cells (*a*) there remains in several places a cytoblastema, which is as yet devoid of any form (*b*).

Each of these cells contains one kernel, and each kernel one nucleolus. It never occurs that several cells are enclosed in one. I once observed on the edge of such a group a kernel (1), which was not enclosed in a cell. In the part which is placed more towards the exterior, the cells were more arranged in rows, and the intercellular substance began to assume a somewhat granular or finely-fibrous appearance.

At the age of maturity, the tissue, when taken parallel to the direction of the fibres, presents a regular appearance. The fibres run parallel, and between them, at regular mutual distances, there are rows of elongated cells, kernels, and kernel-fibres (fig. 140), with which the bundles of the fibres are lined.

I believe I may conclude from this, that in the intervertebral cartilages the kernels are first formed in a shapeless cytoblastema, and that around each kernel a cell is immediately produced; that every cell is formed wholly in itself, and not in the interior of other cells; that the greater part of the cells are elongated in a determinate direction, and are thus placed in rows, the intercellular substance becoming first finely granular, and subsequently fibrous;—that the greater part of the cells disappear, leaving only the kernels, which are, for the greater part, elongated into kernel fibres, whilst the tissue is gradually rendered firmer.

When small and soft pieces of intervertebral cartilage are boiled, they quickly assume a gelatinous appearance. After five hours boiling, they were for the

vertebral fibrous cartilages. (For these, we refer to figs. 138, 139, and 140.)

The elastic cartilages are very characteristically different from the two kinds of which we have hitherto treated. Their main bulk consists of a dense net of very fine elastic fibres (fig. 143), enclosing a great number of isolated cells (figs. 141 and 142). These cells, when boiled, produce chondrin. As regards the presence of these cells, therefore, elastic cartilage resembles true cartilage, which seems to contain the same cells, and consequently the same materials, from which the cells are formed. But there is a real difference between the elastic and the true cartilages, since the great number of elastic threads, which are present in the former, cannot be converted into chondrin by boiling, but remain unaltered.*

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most part dissolved, and the clear filtered solution contained granular kernels and only a very few cells. In the pieces that were left undissolved, the fibres could hardly be longer distinguished.

Large pieces of this cartilage, after having been boiled for 48 hours, were not yet wholly dissolved. The liquid also contained some kernels, which were for the greater part granular, but hardly a single cell.

The solution was evaporated, first treated with alcohol, in which it swelled like a spunge, and then with ether.

Reagents acted upon it in a manner very similar to that in which they act upon chondrin. Thus with—

Tannic acid, ...	*Only a slight precipitate appeared.*
Acetic acid, ...	A large precipitate, mostly disappearing by an excess of the reagent.
Hydrochloric acid, ...	A precipitate, which totally disappeared in an excess of the reagent.
Basic acetate of lead, ...	A gelatinous precipitate.
Neutral acetate of lead,	A white flocky precipitate.
Ferro-cyanide of potassium, Ferri-cyanide of potassium,	No precipitate.
Bi-chloride of platinum,	*A large precipitate not redissolved by an excess of the reagent.*
Alum, ...	*A coherent, flocky precipitate, not redissolved by an excess of the reagent.*
Sulphate of alumina, ...	A smaller precipitate, dissolved by an excess of the reagent.

The other reactions are all the same as those of chondrin, except that glue obtained from the intervertebral cartilages yields an abundant precipitate with bi-chloride of iron (Donders).

* *The elastic cartilage of the ear*, taken from the ear of the same individual

Since the elastic cartilage of the ear, when boiled, produces very little chondrin—the cells of the cartilage being but slowly dissolved when thus treated—it appears that by boiling

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whose rib cartilages we examined, exhibits in the first place this peculiarity, that there is a gradual transition, or rather an imperceptible union of the skin with cartilaginous tissue, so as to cause a slow confluence of the fibres of the skin with the cartilaginous tissue (2), of which the former are more distinctly brought out by acetic acid, and are not easily soluble in potash or sulphuric acid (fig. 141,1), thus showing a similarity with elastic tissue. These fibres gradually separate from one another, inclose a continually increasing number of cartilage bodies, and are insensibly changed into the fibres of the fibrous cartilage. This presents the following appearances.

The entire tissue consists of cells, placed closely together, intermixed with fibres, which in some places surround the cells like rings (fig. 141 and 142). Those that are situated between the cells appear in some places broken off and shortened; perhaps they are bent down to a greater depth. The fibres have a dark colour.

The cells are more or less globular; each cell contains in most cases one kernel, sometimes two or three, or they are replaced by fatty cells. The cartilage bodies, in which the cells of the rib cartilages are enclosed, as I stated before, are not present here. There are no chemical means by which we can obtain the cells of the cartilages of the ear by themselves, as we have seen could be done with those of the rib cartilages by means of potash and sulphuric acid. In the cell kernels a nucleolus is occasionally found.

After having been kept in a strong potash ley for five hours, the cells with their contents disappear entirely on the addition of a large quantity of water, and in the spots where the cells were before observed, empty spaces are left—the remaining mass consisting of exceedingly fine fibres, interwoven like a net, which are not dissolved at all (fig. 143). By this, as by all the other reagents, the latter are affected in exactly the same manner as fibres of elastic tissue. The undulating fibres, originating in the skin, where they take up cells between them, are there woven together like a net, and leave meshes, in which the cells are enclosed. The whole elastic cartilaginous tissue, therefore, is composed of a basis of fibres of elastic tissue and of cells, which are affected by reagents in the same manner as true cartilage. There is, however, this difference between the cells of the elastic, and those of the true cartilages, that the former are less elongated, contain fewer fat cells, and generally a kernel with a nucleolus. They also appear to be more readily soluble in potash.

The fibres of the elastic tissue, which are present in the elastic cartilages, are difficult to be seen. This, however, arises only from their closer texture; for after having been treated with potash and water, they assume the appearance of a fine net (fig. 143). After the tissue has been kept in strong potash and separated from the cells, it still retains its elasticity; which is also the case with that of the cervical ligament. It also resembles that of the latter, after the strong potash has acted upon it for a number of days, viz.:—it becomes gelatinous, divides into small granules, and becomes soluble in water.

true cartilages after the intercellular substance has been dissolved, a tolerably pure solution of chondrin may be obtained, provided the operation be not too long continued.

When the elastic tissue of the ear has been kept in strong sulphuric acid for seven hours, it has assumed a brownish colour, and a gelatinous, swollen appearance. The addition of water makes it contract again; it becomes white and elastic, but soft, and presents itself under the microscope as a compact mass without cells. The places, where the cells were situated, have become much smaller. By their elasticity the fibres have contracted, and thus the apertures, in which the cells were formerly placed, have been closed up. The cells are therefore dissolved by sulphuric acid and water, leaving a granular contents behind, but the fibres remain, having lost their transparency, a change peculiar to this elastic tissue under these circumstances.

A fragment, which was kept for seven hours in strong acetic acid, had retained the cells, and the fibres also were left unaltered. No real change had taken place, except that very large kernels, each with a very distinct nucleolus, had appeared within the cells.

The *elastic cartilage of the epiglottis*, which is considered identical with that of the ear, presents under the microscope a net of fibres similar to that of the ear cartilage, in which very transparent cells are enclosed. The fibres can here be more easily distinguished, and leave some empty spaces between them. The cells are less crowded than in that of the ear, and contain distinct kernels, which are sometimes surrounded by concentric lines. The fibres that are placed between the cells pass imperceptibly into those by which the fibrous cartilage is surrounded. Upon the boundaries nothing but kernels can be seen, which are entirely devoid of cells. Only a few fat globules are present in the cells, the latter being in general very clear and transparent.

After having been kept in strong potash for two hours, the tissue can with difficulty be distinguished. On the addition of water it swells very much and quickly, the cells are dissolved, but the fibres around them are left unchanged.

No real difference therefore exists between this cartilage and the elastic cartilage of the ear.

Joint-cartilages of the sub-maxillary joint taken from the surface, below the serous membrane.

They present numerous cells, packed densely together, separated from one another by fibres. Every cell contains a kernel, and in this kernel again a nucleolus is frequently found, as in the cartilage of the ear. Perhaps the cells in the former cartilage are placed a little closer to each other.

After it has been kept in strong potash for fifty hours, its several parts can no longer be properly distinguished. When water is added, the whole is dissolved, except the numerous threads of elastic tissue. Acetic acid makes them contract into one group, which is the usual effect of this reagent upon elastic tissue.

We found the joint cartilage upon the condyle of the lower jaw of the cow to consist for the greater part of true cartilage, containing mostly round cartilage corpuscles, similar to those of the cartilaginous dissepiment of the nose of a man (Donders and Mulder.)

There are some other tissues known by the name of cartilages, but which cannot be classed either with the true or with the fibrous cartilages. To these belong a mixture of true cartilaginous tissue, fibro-cartilaginous tissue (or elastic tissue), and gelatinous tissue, such as is represented, for instance, by the meniscus of the sub-maxillary joint.*

LL. The Tissue of the Bones.

In a great number of animals we find certain supports of the soft parts, which serve for locomotion, for protection, and for other purposes. When these supports consist of hard substances, viz., of lime-salts united together by gelatinous tissue, they are called bones.

They vary very much in structure; but all have this in common, that lime-salts are enclosed in a tissue which yields glue by boiling. The structure of the bones is to a great extent determined by their form. Those that are long, have medullary cavities in the centre, and the two ends, which are of a looser texture, are similar to the interior of the flat bones. Of the latter the external layers are dense, but between these dense layers, of which the texture approaches in appearance to that of the hard parts of the cylindrical bones, a looser texture is interposed, which is similar to the spungy mass at the extremities of the long bones. This cellular mass con-

* The *meniscus* of the sub-maxillary joint presents numerous bundles of dark fibres, interwoven with one another in different directions, between which are found scattered cells of fibrous cartilages, which are sometimes placed by one another in groups.

After being kept for fifty hours in potash, the addition of water causes the appearance of a large number of fine fibres, which are very transparent, and present themselves as elastic fibres, which belong to the ligamentary tissue; some few cells appear besides. By this re-action, the joint-cartilage we are now treating of may be classed with the elastic cartilage of the ear. After being washed with water the cells are completely dissolved, and only the threads of elastic tissue are left, which become darker by acetic acid.

Strong acetic acid renders it transparent, and makes it appear as transversely cut thick bundles, which in some places are similar to bundles of ligamentary tissue, swollen by acetic acid, interwoven with threads of elastic tissue.

According to these observations, these menisci consist of gelatinous, elastic, and, as far as the cells are concerned, cartilaginous tissues.

sists of solid bony tissue, within which are found small cavities, which have a mutual communication.

In long bones these cavities are towards the interior connected with the medullary cavities; towards the exterior, in the more solid parts of the bones, they are in communication with small cylindrical canals. These are called medullary canals, and in the cylindrical bones they run parallel to the large medullary cavity (fig. 149, 1). They are also connected with one another by transverse little channels (2), and constitute a reticulated system of canals in the solid mass of the bone. Towards the interior these canals become wider and pass into the cells, by which the large medullary cavities are surrounded. In consequence of the large number of these little canals, the longitudinal section of a solid bone has a striated appearance.

These canals are filled entirely, or partly, with a fatty substance, which is probably similar to the medulla of the bone cavities; besides this, they also enclose blood-vessels.

The little medullary canals are placed at short distances from each other (fig. 146), and whilst they are on the one side in communication both with the medullary cells of the great medullary canals in the long bones, and with one another, they are externally connected with the vessels of the membrane of the bone (periosteum).

Radiated lines proceed from the circumference of the transverse section of such a little medullary canal (fig. 147), and at some distance from them we find circular, or elliptic rings, which are formed by an equal number of little plates, of which the medullary canal is the common centre.

Within the elliptic rings, around the medullary canals, there are little cavities (fig. 147, 1), which are called *bone corpuscles*, or more properly *bone-cells*, or *bone-cavities*. These are elongated little spaces, containing numerous radiated fine lines, (these little rays may be seen at fig. 144, 2, and 45, 3,) and placed with their longitudinal diameter in the direction of the concentric rings around the transversely cut medullary canal. They are situated upon this curved line at regular distances, and around them there is a second, and

a third row in succession (fig. 147). According to some, they contain a granular substance, which dissolves with effervescence in dilute hydrochloric acid, and is considered to be a precipitate of bone salts, deposited in a cavity. But they are rendered very distinctly visible by the use of Venice turpentine, and hence it would appear that they are rather to be taken for cavities, into which the turpentine, which penetrates the remainder of the mass, cannot enter, although these cavities actually contain carbonate of lime.

Between the little medullary canals and the cells of the bones, just mentioned, we find gelatinous tissue united with the bone salts. This tissue has the appearance of little plates, pressed very firmly together, and consisting of an intimate combination of the gelatinous substance with bone salts. This part of the bony matter is of a finely granular structure, and semi-transparent (fig. 145, 2).*

* *The human thigh-bone.* A transverse section, ground into a thin plate, exhibits (fig. 146) round or elliptic apertures (1, 2, 3, 4,) which are the sections of the little medullary canals, and which are in several places connected together by dark channels (5). The latter are the transverse medullary canals, which, together with the longitudinal canals, constitute a net of intercommunication throughout the solid substance of the bone. Towards the interior, the number, and generally also the size, of the sections of the longitudinal medullary canals increase (3, 4). There are two distinct systems of bone-plates; the one lies parallel to the surface (6), the other concentrically round the medullary canals (7). All the exterior plates run parallel to the surface of the bone; and the medullary canals that are placed near the surface (1, 2) possess either a few concentric plates only, or none at all.

Between these plates of the bones we observe small, dark, generally oblong spots (fig. 144, 1), (bone-corpuscles, bone-cavities, bone-cells,) which, on the focus being a little removed, soon loose their dark appearance, a proof that they are not wholly untransparent. In reflected light they appear white. By the application of thick Venice turpentine these spots become darker at first, and there appear very distinctly a great number of ramifying rays (2), which proceed from them in all directions, and unite with those of the neighbouring bone-cavities. Thin turpentine enters quickly into these cavities, and into the fine canals that proceed from them, so as to render them almost wholly invisible.

Between the plates with which the little medullary canals are surrounded, we find similar small cavities, of which the rays extend through the plates towards the little medullary canal (fig. 147).

On the longitudinal section, the little cavities of the bone also appear in most cases oblong or elliptic.

When taken parallel to the surface, they most frequently approach the cir-

When bones are digested in dilute hydrochloric acid, they leave gelatinous tissue behind, having the form of the bone. They are then deprived of the greater part of their salts, have become flexible, and, with the exception of the vascular coats,

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cular form. They have therefore the shape of a lens, and their broadest surfaces are turned towards the plates of the bone. They may be considered as cells, or cell-like spaces, flattened between the bone-plates.

The human os vomeris. The thinner part of this bone, even before having undergone any preparation, presents the bone cavities very distinctly, although here still more layers are found. When the piece is ground a little, the cavities parallel to the surface (fig. 145, 1) appear in most cases circular or slightly elliptic. Here, especially, it is evident that they are hollow. The mere addition of water renders them more transparent than the remainder of the mass, which has a finely granular appearance (2). By thick Venice turpentine they become very distinct, especially in the beginning, and the rays which proceed from them (3), appear distinctly as little canals. Gradually, however, as this liquid penetrates into the cavities, they become less distinct, and disappear almost entirely. When a thinner kind of turpentine is used, this takes place almost immediately. It is very easy to follow under the microscope the progressive motion of the turpentine between two glass plates.

The human thigh bone digested with dilute hydrochloric acid. On the transverse section of the solid substance both the systems of bone plates may be seen much more distinctly (fig. 146). Under a high magnifying power, they present themselves as alternating dark and lighter lines. The longitudinal section presents the same appearance (fig. 148). The cavities appear to be less dark, yet they may be easily distinguished. The various sections prove that here also they have generally a lenticular form. In some of them we perceived one or more small bodies (fig. 148, 3).

The rays of the bone cavities are very distinct in the concentric plates round the little medullary canals. They do not seem now to run in curved lines, as was the case before the bone was digested with hydrochloric acid (fig. 147).

On the longitudinal section the bone cavities (fig 148, 1) appear elliptic, and the plates (2) look as if pierced by fine parallel canals, which are probably nothing else than the fine canals that proceed from the cavities.

By a less magnifying power the longitudinal section presents the longitudinal medullary canals (fig. 149, 1), which are frequently in mutual communication by lateral branches (2).

The human *calf bone*, extracted with hydrochloric acid, is in every respect similar to the former. It appears, in a longitudinal section, that the longitudinal medullary canals have here less mutual connection by transverse canals, than those in the thigh bone.

The *thigh bone of a frog*, extracted with hydrochloric acid, presents only one central medullary canal on a transverse section. This entire bone may be considered as one single medullary canal, surrounded by its concentric plates.

may be almost wholly converted into glue by boiling, &c. The structure of this tissue is so very laminar, that the plates may be separated from one another by means of a pointed body, both those that are situated round the medullary canals and those that do not belong to these canals. When the bones

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The rays, which proceed from the medullary canal, and pierce through the plates of the bones, are very distinctly visible. The bone cavities near the surface are very large, and contain in most cases very distinct kernels, and even sometimes cells.

A human thigh bone extracted with hydrochloric acid. On a thin longitudinal section, which has been kept for five hours and a half in a strong solution of potash, the lines by which the bone plates are surrounded have become granular, although they are still easily recognised. The bone cavities are not visible. On the addition of water the bone plates become less sharply defined; the cavities, on the contrary (fig. 150, 1), become distinctly visible, swell a little, and each of them appears to contain a kernel, or even several in a row, sometimes even a cell (2). They resemble the cartilage corpuscles existing before ossification has taken place, and are situated in rows between the bone plates, in the same manner as the cartilage corpuscles in the neighbourhood of the ossified plates, during the process of ossification.

A section parallel to the surface, after having been kept in strong potash ley for five hours, became very soft. The bone cavities are visible without the addition of water, have a globular form, and present a granular appearance. When water is added, nearly the whole is dissolved; only a few small corpuscles being left, which resemble bone cavities. These cavities, therefore, or part of them at least, appear to contain walls of their own, and to be actually cells. One of them revolved in the liquid, and appeared very flat on the other section. They do not, therefore, swell into globular cells, which is perhaps owing to their walls being pierced through.

While examining a section, taken parallel to the surface, we observed, besides the bone cells, other large, roundish, floating bodies, which presented a cellular structure, and were untransparent. Probably these were derived from the contents of the medullary canals, and are not to be confounded with the cells of the bone.

A transverse section, after having been kept in potash ley for five hours, presents a concatenation of spheres, of a tolerably large size, especially in the neighbourhood of the medullary canals. They are of unequal size, and must undoubtedly be considered as little soap-globules, formed by the combination of the potash with the fat of the medullary canals, and insoluble in the excess of potash.

A transverse section, which has been kept for five hours in strong sulphuric acid, had become for the greater part transparent, except in those places where medullary canals exist. The structure is not recognisable. On the addition of water, the bone cavities reappear, each containing one or two kernels, and sometimes a row of granules. (Donders and Mulder.)

have been digested in acid, the medullary cavities and the cells of the bones are visible.*

We have therefore to consider the bone-tissue as consisting of two sets of little plates, one of which (fig. 146, 7) surrounding the little medullary canals, which are placed parallel to the axis of the bone, consists of a number of little hollow cylinders enveloping one another, between which a large number of ramifying cells are placed; whilst the other set (6) encloses the canals and cells, and connects them together. The fundamental substance, however, of the soft bony matter may be considered as a compact ligamentary tissue, without any distinct structure, containing both cells and little vessels. The cells constitute the so-called bone-corpuscles, and may be compared with the cells of the cartilage, the shapeless fundamental substance or base with that of the cartilages, whilst little canals remain, as ossification takes place, around the vessels.

The type, therefore, of the form of the bony tissue is found in true cartilaginous tissue, which has obtained blood-vessels.

The tissue of the bones is very loose, and in the large medullary cavities of cylindrical bones large cavities are found. A great number of blood-vessels and fat-cells are accumulated here. The medulla penetrates through the medullary canals, and so through the whole solid mass of the bones. Generally the fat in the bones is more fluid than that which is found

* Von Bibra has analysed the gelatinous tissue of the bones (Ann. der Chemie und Pharmacie, April, 1844, p. 151), and found:—

	Fossil bones.	Ox bones.
C	50.401	50.130
H	7.111	7.073
N	18.154	18.449
O	24.335	24.348

This is the same composition as that of gelatinous tissue, found by Scheerer (see p. 350). These results, however, have given too much hydrogen, as was the case with those of Scheerer with gelatinous tissue.

In the recently published work by Von Bibra, entitled, *Die Knochen und Zähne*, the author has added greatly to our knowledge of the bones; and besides several analyses of this gelatinous tissue, p. 396, he has mentioned, that the gelatinous substance of the bones contains on an average 0.216 per cent. of sulphur, which sulphur is not found in boiled glue.

in the other parts of the animal body, and contains a large portion of elain. In the spungy extremities, and in the looser parts of the flattened bones, this fat is to a great extent replaced by a reddish semi-fluid mass, of which the composition is not yet properly known. It would appear, that this mass contains a large portion of extractive matters.

Arteries run into and veins proceed from the bones. They are spread through the whole substance of the bones, after having first entered into the medullary cavities, whence they extend themselves through the little canals of the bones mentioned above. Besides these, a great many other small arteries find their way from the periosteum, a membrane with which the bones are externally surrounded, into the solid bony substance, and passing through the little channels, are diffused through the mass uniting with the little vessels just mentioned.

There are two kinds of bone salts: first, those belonging to the blood, the medulla, and other soft or liquid parts, which are therefore not essential to the bones themselves; and, secondly, those that must be considered as part of the bones properly so called. The latter are, phosphate of lime, having the formula, $8\,Ca\,O\,3Ph\,O^5$ (this salt is, according to Graham, composed according to the formula, $3\,Ph\,O^5$, $8\,Ca\,O, H\,O$, and must therefore be considered as $Ph\,O^5$, $3\,R\,O$, or a tribasic-terphosphate); with carbonate of lime, phosphate of magnesia, carbonate of magnesia, and fluoride of calcium, the proportion of the latter being very minute. The greater proportion consists of phosphate of lime; then comes carbonate of lime; the quantity of the others is much smaller. The proportion of these salts varies with the difference in the kind of bones, and in age. Berzelius found in 100 parts of human bones, 33.3 parts of organic matter and 66.7 of inorganic matter, the latter consisting of 53.04 per cent. of phosphate of lime, 11.30 per cent. of carbonate of lime, 1.16 per cent. of phosphate of magnesia, and 1.20 per cent. of soluble salts from the blood, &c. The 33.3 per cent. of organic matter contained 1.13 per cent. of substances insoluble in water, consisting of the coats of the vessels, &c. The rest consisted of gela-

tinous tissue and of the soluble part of the medulla. The proportion of inorganic substances is stated to be different in different bones; the proportion of lime-salts, for instance, being greater in the dense than in the looser parts of the cylindrical bones. Thus Frerichs found

	Spungy bones.		Compact bones.	
Organic substances	38.22	37.42	31.46	30.94
Phosphate of lime	50.24	51.38	58.70	59.50
Carbonate of lime	11.70	10.89	10.08	9.46

A great many similar determinations have been made by Von Bibra. (See *Die Knochen*, &c.)

In the disease which is known by the name of rhachitis (rickets), the lime-salts decrease in quantity, which has the effect of making the bones flexible; in old age these salts increase, and hence the bones are rendered fragile.*

We have mentioned before (p. 329), that before ossification has taken place, the gelatinous tissue of the bones when boiled yields chondrin, and not glue or gelatine. That tissue of chondrin (true cartilaginous tissue) contains blood-vessels, and from these a two-fold change commences, first, a change of chondrin, or cartilaginous tissue, into gelatinous tissue, and at the same time a deposition of bony matter. These two changes take place simultaneously, and as they are also perceived in the rib-cartilages, there is a relation of causation between them. The nature of this relation, however, is yet unknown. It would appear, however, that as the blood-vessels in the cartilages are developed, the substance which they form becomes soft, and very much impregnated with moisture, and that the change of materials being thus as it were prepared, the chondrin of the bones is converted into gelatine, whilst at the same time, bone-salts are supplied from the blood, to be simultaneously deposited within the gelatinous tissue, when in the act of production.

The proportion of the inorganic and organic constituents

* Bones have been analysed by several chemists, viz., *Marchand*, Journal fur Pract. Chemie, B. 27, S. 86. *Nasse*, ibidem, S. 274. *Frerichs*, Ann. der Chemie und Pharmacie, B. 43, S. 251. *Rees*, Philosoph. Magazine, 1840, Jan. *Stark*, Edin. Medical and Surgical Journal, 1846.

in bones does not indicate in what way the former are combined with the gelatinous tissue, because we find in bones, besides other salts, carbonate of lime also, and this certainly does not form a chemical combination with the gelatinous substance. The phosphate of lime is the only salt that can here be taken into account, and experiments by Frerichs* and Von Bibra† seem to show that this salt does actually form such a combination, although the results of the analyses of these combinations of gelatine and phosphate of lime do not all agree. From a mixture, consisting of a solution of gelatine from bones and of phosphate of lime (bone-earth) in hydrochloric acid, Frerichs obtained precipitates by ammonia, which contained respectively 28.2—27.4—24.4 per cent. of gelatine, whereas, according to the formula for gelatine, as established by me, this compound ought to contain 26.2 per cent. Von Bibra found in similar precipitates from 23.25 to 24.7 per cent. of gelatine.

It would appear, therefore, that, provided the experiment be made with due precaution, there exists a combination of gelatine with phosphate of lime, which has a constant composition. This compound, assuming the composition of phosphate of lime, as given by Graham, to be correct, may contain 1 equivalent of gelatine ($= C^{13} H^{10} N^2 O^5$) in place of 1 equivalent of water, and may therefore be considered as

$$3\ Ph\ O^5 + 8\ Ca\ O, C^{13} H^{10} N^2 O^5$$

instead of $3\ Ph\ O^5 + 8\ Ca\ O, HO$.

I must remark here, that I myself have not made one single experiment of this kind, as Von Bibra seems to think (p. 63), but that I have drawn this conclusion from those made by him and Frerichs.

We have, therefore, every reason to consider the phosphate of lime in bones as being chemically combined with the gelatinous substance, although it will probably not be possible entirely to overcome the difficulties attending the determination of this combination.

We are yet uncertain in what part of the bones the car-

* Annalen der Chemie und Pharmacie, Sept. 1842. S. 252.

† Die Knochen. S. 62.

bonate of lime is found. Von Bibra follows those who preceded him in assuming (p. 45) that this salt is found in the bone corpuscles, and that it exists besides in their ramifications.

It is difficult to decide this matter. As yet no fixed proportion has been found between the phosphate of lime and the gelatinous substance in bones which are fully developed; and if there were only one chemical combination of these two substances, this proportion ought to be found constant in all kinds of bones.

The analyses of bones, however, that have as yet been made, do not indicate such a simple combination. If, however, this could be shown, as far as developed or full-grown bones are concerned, then it might be asked what the composition of bones is in old age, when the proportion of phosphate of lime is constantly on the increase. It is possible, however, that there are other chemical combinations of phosphate of lime and gelatine, besides that of equal equivalents, and that, for instance in old age, a basic compound may gradually be formed. Finally, no account has yet been given as to the manner in which either carbonate of lime or the other salts exist in the bones.

MM. Fat Tissue (Tela adiposa).

Fat may be called, in the entire meaning of the word, an organised substance, as strictly as the elementary tissues of the animal body, of which we have hitherto treated. It neither lies free in the cavities of the ligamentary tissue, nor can it be viewed as a secretion of the latter, but is contained in peculiar cells, which exist independently in its cavities.

Fat cells are membranaceous little bags, closed on every side, a large number of which is often contained within one and the same cavity of the ligamentary tissue. They are globular, have a very glossy surface, and a similar border of a pure white colour, and they are therefore to be considered as organs of a peculiar kind. Generally, the membranes of the fat cells are found hanging like bunches of grapes on small ramifications

of blood-vessels, which form a capillary system in the exterior membrane. In the living body these membranes are filled with liquid fat, which, when removed from them,—by means of ether for instance,—assumes a crystalline appearance.

The fat cells may easily be distinguished from drops of fat, as the latter can be made to flow together, and are not globular, but lenticular. The size of these drops is variable, whereas the fat cells in the same organ are not very different in this respect (fig. 151).

The membrane of the fat cells is in most cases very thin, and sometimes contains one, seldom two kernels. In some cases, viz., in emaciation, according to Todd and Bowman, lines, which are considered as crystals of solid fat, radiate from one point of the surface. When the cells are treated with ether, the fat is extracted through the membrane, which then collapses like an empty bag (fig. 153). According to Henle, acetic acid dissolves the membranes and makes the contents of several cells flow together. This has not been confirmed by our observations, as we found one of the two cellular membranes which cover each other insoluble both in strong acetic acid and in potash. The exterior membrane, namely, appears to be soluble, but another below this, which encloses the fat, is insoluble (fig. 152).

These fat cells are found in the human body, below the skin in the loose ligamentary tissue, in the omentum and mesentery, and on several other places.*

* The *fat cells* from the kidney beds of a pig are very large, oblong, and filled with a granular contents. Those from a sheep are angular. Strong acetic acid loosens them entirely, and they are made to float in the air (fig. 152). The kidney beds of a cow also give poly-edric fat cells, which are equally loosened by strong acetic acid, and hence appear to contain a soluble ligamentary substance. Those of a calf, which are of a smaller size, have the same properties. Those from a human body are still smaller (fig. 151). In none of these can any kernels be seen (fig. 151).

Pork suet, (hog's lard), when extracted with ether, leaves very thin transparent membranes, having a granular structure (fig. 153). They have become collapsed and lost their cellular form. Acetic acid does not dissolve them nor change their granular appearance.

The cellular membranes of the calf are not dissolved by a strong potash ley. The cells retain their form even after the action has continued for an hour.

The fat cells of a sheep, when extracted with strong acetic acid, have their

Fat is easily produced by abundance of nutriment, especially of food that is rich in fat, and it is re-absorbed when there is a want of nutriment in the body. In some animals fat accumulates about the time that the winter sleep commences, and decreases again very much during that sleep. This periodic change of the quantity of fat involves the production of the fat cells in some obscurity. We do not know whether these cells disappear entirely, or merely the fat which they contain, although the latter is most probable. Neither is it known of what kind of chemical substance the membranes of the fat cells are composed. It is certain, however, that they differ from fat, and are insoluble in alcohol or ether. The outermost of the two membranes, which enclose each other, seems to be gelatinous tissue; the innermost does not consist of this substance.

The fat contained in these cells is different in different animals. It consists of the fatty acids, enumerated before (p. 249), in most cases combined with oxide of lipyl. They are frequently mixed together, for instance, margarin and elaïn in the human body, &c.

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membrane also rendered granular and untransparent. This reagent makes the membranes give way, retaining the shape of the fat cells, but they themselves remain unaltered. Hence it appears that there has been dissolved a substance by which the cells are held together, and which, enveloping the whole cells, must be considered as a second cellular membrane. The interior membranes are insoluble in acetic acid; neither are they dissolved nor altered by a strong potash ley, not even after the addition of water. They remain equally unaffected when digested with strong potash at a temperature of 176° F., and still continue so when water has been added. The cells, however, are separated from one another, showing that the substance by which they were kept united has been dissolved, whilst the cells have been deprived of the fat which they contained. Not even a trace has appeared of any other contents, but fat.

The *fat cells of a sheep*, taken from the interior of the belly, were kept in strong potash for seven hours, and remained unaltered. By the addition of water, the exterior membrane first swells, is changed into a fine granular substance, and is then dissolved. The cell retains its form, however, and floats in the liquid unchanged. A second membrane, therefore, insoluble in potash, incloses the fat. This membrane can also be rendered visible by pressure.

Acetic acid renders the exterior covering of the fat cells very transparent and swollen, but the fat cell with granular contents undergoes no further change. We have not been able to make out of what these membranes consist. (Donders and Mulder.)

In animals the general mixture of fats is not always the same. There may even be a considerable difference in the proportions of their component parts. The kidney-beds in cows, for instance, contain a much larger proportion of stearin than the fat of the ligamentary tissue below the skin of the same animals; whilst, on the contrary, the proportion of elaïn is in great excess in the medullary cavities of their bones. The membranes of the fat-cells, therefore, take an active part in the formation of fat, and are not merely the receptacles of a generally diffused fatty matter.

Spermaceti, which is found in a cavity of the head of the Physeter macrocephalus, and the peculiar kinds of fat existing in the brains of all animals, are ample proofs of the accuracy of this statement. It is probable, however, from the comparative table given at p. 255, that peculiar fats may easily be formed from the more general kinds, by the addition or subtraction of oxygen, which is carried into the blood through the lungs.

In a *histological** point of view, however, we must distinguish two kinds of fat in the organism,—viz., that which is enclosed in the cells just mentioned, and that which is chemically combined, that is, united with other substances. We have seen that the former is found in the loose cellular tissue, which is so very generally diffused; the latter is present in the brain and in the fluid parts of the body.

The chyle contains the fat which is absorbed from the food. The reaction of the chyle is alkaline, and therefore the neutral fats of the food are wholly, or in great part, saponified, either before they enter into the blood or shortly afterwards. With the exception of those fats that are not capable of being converted into a soap, such as cholesterine, no neutral fats have been found in the blood, as long as it remains in a healthy condition.† It contains, therefore, margarates, eleates, and in many animals stearates, and other soaps of soda. These compounds of fatty acids with bases, soluble in water, are the materials which serve for the pre-

* Histology is the doctrine of the elementary parts of plants and animals.
† See Simon. Med. Chemie, ii. p. 230.

duction of the fat-tissue and the fatty substances that are in chemical combination, existing in the brain, the liver, and the kidneys. These compounds are to be worked up, and, with the separation of their alkaline base, soda, must be reconverted into neutral fats by combining with oxide of lipyle or other bodies. In the substance of the brain, for instance, and in the parenchyme of the liver and the kidneys, we find fats intimately combined with albumen, whence these substances, on being rubbed with water, form an emulsion, similar to that obtained by crushing almonds or linseed, and rubbing them in the same way. A similar combination of fat and albumen is found in the bile, which evidently contains fatty acids; but so intimately combined with the bile, that, although there is an excess of soda present, acids cannot produce a precipitate of fatty acid in that secretion.

The separation of the soda from the fatty salts which are present in the blood, takes place in the capillary system, by the influence of the carbonic acid which is produced there. The fatty acids, on being set free, must at the same place find oxide of lipyle, with which they can reproduce neutral fats. (See p. 255.)

When fats in the animal body are produced from those that exist in the food, there must happen in every case a conversion of neutral fats into fatty acids, and again of the latter into neutral fats. But there must take place besides a change in the relative proportions of margarin and elaïn; in the human body, for instance, the fats of which contain margarin and elaïn in a definite proportion—if the requisite proportion of these is not supplied to it in the food. It is evident, for example, that olive oil, which contains much elaïn and but little margarin, cannot be converted into human fat without previously undergoing a change. Further, there must take place a conversion of one fatty substance into another; for instance, of margarin into stearin, or *vice versa*; and lastly, according to Liebig's experiments, a conversion of starch (dextrin and sugar?) into fat.

The latter substances must lose oxygen, in order to be converted into fat, as they do in the vegetable kingdom.

Consequently they are produced by de-oxidising influences, whilst under the same circumstances fats containing little oxygen are formed from such as contain more. When, for instance, cholesterin, which exists in the blood, in the bile, and in the brain, is formed from margaric acid, the latter must lose a great deal of oxygen and hydrogen, and take up carbon; thus—

Margaric acid, $C^{34} H^{34} O^3$
Cholesterin, $C^{37} H^{32} O$.

The fats of the animal body are therefore subject to an alternate oxidation and de-oxidation. The former takes place, no doubt, in the lungs; the latter in the capillary system: both, therefore, in the blood. After having been prepared, according to the circumstances in which they were placed, they are removed from the blood and deposited at determinate places, to be again taken up from thence, and,—after having previously formed unknown intermediate products, which must contain a continually increasing proportion of oxygen, and ought to exist in the blood,—finally expelled by the lungs in the form of carbonic acid.

If, for instance, butyric acid is to be formed from margaric acid in the body of a cow, then the comparison

Margaric acid, $C^{34} H^{35} O^4 + O^5$
$=$ Eleo-butyric acid, $C^{34} H^{31} O^5 + 4HO$

shows that five equivalents of oxygen must first be absorbed to produce eleo-butyric acid; and when the latter acid is afterwards to be converted into butyric acid, the formula of

Eleo-butyric acid,		C^{34} H^{31} O^5	lessened by
Four atoms of butyric acid,		C^{32} H^{28} O^4	
Leaves	- -	C^2 H^3 O^1	which, with
6 of oxygen,	-	- O^6	
Give	- -	C^2 H^3 O^7	$= 2CO^2 + 3HO$

—or six equivalents of oxygen are required to form, with the elements separated from the liquid fat of butter, two equivalents of carbonic acid and three of water. This change takes place out of the animal, by exposing the eleo-buty-

ric acid to the air; but it illustrates, nevertheless, in how simple a manner the fats in the animal body may be changed.

That margarin and elaïn may be converted into stearin by the agency of de-oxidising influences, even although entirely without the organism, is well known since the investigations instituted on the subject by Beetz*; for he has found that the *adipocire* of Fourcroy and Vauguelin consists of stearin, mixed with stearic soaps. The fatty matters of the dead bodies of men become harder and more solid in the course of time, and are converted into stearin, in conformity with the views stated regarding this change at p. 251, which is applicable at least to margarin.

The formation and absorption of fats are therefore a very important source of change of materials in the animal body, the influence of which is not exclusively confined to the formation of new products, as this very formation serves in its turn to excite other actions. For these fats are not only, after being taken up from the plant, and for a time incorporated with the animal body, again expelled from it in the form of carbonic acid and water; but they are to be considered as highly important substances, eminently fitted for the production of a variety of other bodies, and, whilst the latter are in the nascent state, to be at the same time a powerful source of action, by which new chemical forces are brought into play.

It is to be regretted that our knowledge of the fats that are found in various animals, is still so exceedingly limited, that we are even unacquainted with the constitution of elaïc acid. For this reason, we may truly say that, for the present, any attempt at a comparison of the fats with each other is fruitless and unprofitable.†

* Poggendorf's Annalen, 1843, N. 5, S. 111.

† It has been more recently shown by Gottlieb, that the liquid fat of butter is identical with olive oil, &c., and that the elaïc acid it contains is represented by $C^{36} H^{33} O^3$. It absorbs oxygen with great rapidity from the air, and hence the reason why it has never been obtained, and therefore never analysed in a pure state by preceding chemists.

Compared with the formula for margaric acid, adopted by Mulder, we have the following difference :—

From what has just been said, it appears that the formation of several fats in the animal body must be preceded by deoxidation, especially in the case of fats which are to be produced from starch. (See p. 264.) However fully we may be acquainted with the source of oxidation (viz., respiration), we are as yet entirely in the dark regarding the sources of deoxidation. All we can do is to indicate general instances, but we can offer no explanation for any special case.

It seems at first an absurdity to suppose that de-oxidation should take place in an organic whole, into which there is a continual influx of oxygen; and yet it is unquestionable, that many substances do undergo de-oxidation in the animal body; for instance, the one from which cholesterin is formed, which substance is not present in any vegetable food.

This de-oxidation is no doubt brought about by means of some other substance, requiring oxygen for its formation. We are acquainted with some of the substances that do actually exercise a de-oxidising influence in the animal organism,—fruit-sugar, inulin, &c. When, for instance, inulin is dissolved in warm water, and the solution mixed with acetate

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	C	H	O
Margaric acid, ...	34	34	3
Elaïc acid, ...	36	33	3
Difference, ...	— 2	+ 1	

Or elaïc acid must lose 2 of carbon and gain 1 of hydrogen to become converted into margaric acid. This may be effected by the agency of 3 of oxygen and 1 of water. Thus, to

	C	H	O	
1 of elaïc acid, ...	36	33	3	
1 of water and 3 of oxygen, ...		1	4	
And we have, ...	36	34	7	
Deduct now 2 of carbonic acid,	2		4	and
1 of margaric acid,	36	34	3	remains.

Thus, when the liquid elaïc acid of the food is eaten, two equivalents of carbonic acid are given off—breathed away probably—in order that the margaric acid of the human body may be formed from it. I have given some other illustrations of this point in the new edition of my *Lectures on Agricultural Chemistry and Geology*, recently published.—*J.*

of lead and ammonia, lead is separated in the metallic state; and when fruit-sugar is heated with salts of copper and other metals, these salts are deprived of their oxygen. The inulin even takes the acetic acid from the oxide of lead, and the latter, after being isolated, is deprived of the whole of its oxygen, by which part of the fruit-sugar, which exists in inulin, is converted into formic acid. When one equivalent of this sugar is in this manner converted into formic acid, twelve equivalents of oxygen must be taken from some other body; some metallic oxide, for instance. Thus, if from

1 equivalent of fruit-sugar, ...	$C^{12} H^{14} O^{14}$
We deduct 8 equivalents of water + 6 equivalents of formic acid, ($C^2 H^1 O^3$) ...	$C^{12} H^{14} O^{26}$
There remain	O^{12}

Now, as there is a continual decomposition of organic substances going on in the animal body, the result of which is the production of carbonic acid, it is evident that oxygen is supplied, not only by the air inhaled during respiration, but also by substances that are present, and can yield other products by losing oxygen. The oxygen derived from respiration, as far as it is available, oxidises the carbon and hydrogen of the substances that are in the act of oxidation; but whenever it is not present in such a quantity as is required for the decomposition of substances, of which the constituents are in a state of motion, it is taken from other substances that are close at hand, and in this manner a process of deoxidation in the animal body is carried on. The results of this must be the production of fats,—for instance, from starch—and the formation of fats that contain but little oxygen,—that of cholesterin, for example—from such as are richer in oxygen, such as elaïc acid.

That there is a power of de-oxidation operating in the organism, is proved by a great number of phenomena. It commences in the primæ viæ, where the disengagement of sulphuretted hydrogen from sulphates is observed. This de-oxidising action continues everywhere except in the lungs, as

appears, among other examples, from the presence of metallic mercury in several tissues, after a protracted use of preparations of this metal.*

NN. The Tissue of the Muscles.

That class of organs which exhibit reaction when stimulated by various agents, and especially by electricity;—which are for the most part under the control of the will, and which are susceptible of contraction and elongation, are called muscles They consist of different kinds of tissues. In the well-known red muscular mass of the body, we find a quite peculiar tissue, composed of striated bundles. To this kind belong the voluntary muscles and the heart. In these bundles fibres are found, which seem to consist of two different substances, of which the molecules, being deposited alternately with each other, form a thread of a granular appearance (fig. 158 and 161, 2.) Numbers of these fibres, inclosed in a little tube, unite together into little bundles (fig. 155 and 157, giving a view of the transverse section), and a number of these bundles is again united into larger ones by means of ligamentary tissue (fig. 154, 2, and 156, 2). These larger bundles are in their turn held together by ligamentary tissue, and so this union proceeds, until the whole mass of muscles is produced, consisting of fibres and ligamentary tissue with vessels and nerves interwoven through the mass.

The first or smallest bundles are called the primary bundles of the muscles. Often, though not always, they are enclosed in a thin, more or less granular envelope, which resists the dissolving action of acetic acid longer than the fibres of the primary bundle themselves, although at last it is, like them, dissolved, after having first become gelatinous.

This muscular tissue is entitled to our special attention,

* Both this and the action of calomel and corrosive sublimate, between which, as physicians know, the difference of action is exceedingly great, render it impossible to accept the idea of Liebig stated in his Animal Chemistry, that calomel acts in the organism only by its being converted into corrosive sublimate.

because it is so generally diffused through the organism.* The fibres which are called primary, of which 50 to 100 and upwards are enclosed in a little tube, have been assumed to be fibrin, an assumption which as yet requires to be proved. It is

* *A transverse section of the Semitendinosus in the human body* (fig. 154). It presents primary bundles packed closely together (1), of a more or less cylindrical form, flattened against each other so as to assume a multi-angular appearance. A large number of them is united into a secondary bundle, which is surrounded by cellular tissue (2) (perimysium), and isolated from the next. This cellular tissue, which becomes very loose and swollen by the action of acetic acid, presents small elongated kernels and kernel fibres, and in some places bundles of nerves and stems of blood vessels.

When examined under a higher magnifying power (fig. 155), every bundle presents the section of the primary fibres in the form of little dark points. On the addition of acetic acid the whole bundle swells, the points separate more from one another and become more distinctly visible. It would appear, therefore, that it is chiefly the substance between the primary fibres which swells under the action of acetic acid. Generally speaking, no kernels are visible in the bundle; here and there a single one may be seen lying on the sarcolemma, which may, however, be better seen on a longitudinal section. Many of the bundles of muscles are more or less inverted by the act of swelling, and they now distinctly exhibit their transverse lines. No double lines can be seen on the sarcolemma.

A transverse section of the femoral muscles of a frog. The primary bundles are larger and packed together still more closely than in the human body. They have most frequently a cylindrical or multi-angular form; in every angle where three bundles meet, the section of a capillary vessel may be seen more or less distinctly. The primary fibres are distinctly visible, especially after the addition of acetic acid. We perceive besides a considerable number of kernels diffused between the primary fibres in the bundles. In this section the form of the kernels is either round or angular.

The same taken from a very lean frog. The primary bundles are in general smaller and of very different sizes (fig. 156). The smallest (1, *a*) are found especially near the perimysium (2); the sections are often perfectly round, and the bundles are therefore cylindrical. Kernels (fig. 157, 1) and primary fibres (2) are rendered very distinctly visible in the bundles, after the addition of dilute acetic acid; they are also found in the middle part of the bundle. In those of a smaller size (*a*) the primary fibres are placed very near each other. By emaciation, therefore, the primary bundles become thinner, it being chiefly the substance between the primary fibres that disappears.

The same muscles from a cow, are similar to those of the human body; only the primary bundles are a little larger.

The same from the calf. Here the same muscle as that from the cow presents primary bundles of a much smaller size, and hence the number of these bundles, may, in the subsequent growth of the muscles, remain the same. Both in the cow and in the calf it is the exceptional case to find nuclei inclosed in the bundle between the primary fibres.

certain that these fibres do not consist of one simple organic substance, but must be considered as composed of two substances, performing different functions in the organism. The

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A longitudinal section of the primary bundles of all the muscles mentioned, in the fresh state, presents both longitudinal and transverse lines (the former being the primary fibres). These lines are usually straight and regular, but sometimes running zigzag. Where the primary fibres are more distinct, the transverse lines are less so, and *vice versa*.

On applying dilute acetic acid, there appear a great many elongated kernels upon and in the primary bundles of the muscle of the frog (compare fig. 159), but on those of the other animals mentioned, the number of these kernels is but small.

The primary muscular bundles of the psoas of an almost full-grown fœtus are very narrow, and the transverse lines are placed far from each other, so as to render the distance between three of these equal to the whole breadth of the bundle. On the addition of acetic acid, the muscular bundles become very transparent, so as to make it scarcely possible to distinguish the boundary lines of two adjoining bundles. The transverse lines are also difficult to be seen. On the edges of the primary bundles we perceive elliptic kernels, placed at considerable distances from each other. These kernels appear to be situated on the outside of the sarcolemma.

A thin layer of the anterior muscles of the thigh from a living frog readily gives to view distinct primary bundles, with their primary fibres and transverse lines. Between every two neighbouring primary bundles we perceive a capillary vessel filled with blood corpuscles, and in various places connected with others by means of a transverse branch, which lies across the direction of the muscular bundles. It is difficult to observe any separate nerval fibres between the muscular bundles. In the perimysium we perceive small trunks of nerves, some of which consist of only two primary fibres, extending over a very large space.

An oblique longitudinal section of a primary bundle of the dried muscle of a frog (fig. 158), after being moistened with water, presents on its thickest part distinct transverse lines, passing on the thinner side into a row of granules. The primary fibres are formed by these granules being united into longitudinal rows, and the striated appearance of these fibres arises from the granules being placed next and upon each other.

The muscles of a frog, kept in strong acetic acid for ten hours. The bundles (fig. 159) have become transparent and much swollen; the primary fibres are scarcely visible; the transverse lines very conspicuous, and the kernels distinct, although not more so than after a short action of dilute acetic acid. After fifty-eight hours action no further change has occurred. Between and above the bundles a capillary vessel is visible, in which a row of kernels of the blood corpuscles is found.

The muscle of a cow kept four days in strong acetic acid. The whole has become very gelatinous; the transverse lines are still distinct and bent; but the primary fibres cannot very well be seen, and the kernels are also with difficulty distinguished.

one constitutes globules that are larger than those of the other. Both kinds of globules are arranged alternately, and hence the fibre may be almost regarded as a pearl necklace, of

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The muscle of an almost full grown fœtus, kept in strong acetic acid for two hours. The primary bundles are much swollen and pale; the transverse lines easily distinguished; the primary fibres not perceptible, the kernels also a little pale.

The muscle of a frog, kept for twenty-four hours in a closed bottle with strong sulphuric acid. It has swollen into a jelly; the primary bundles have retained their boundary lines, apparently indicating that the sarcolemma has not been dissolved, but of primary fibres or transverse lines no trace can be seen. On the addition of a large quantity of water, the mass becomes white and contracts; and when now placed under the microscope, the primary fibres immediately make their appearance and present granular swellings in the direction, and at the distance of the transverse lines.

The muscle of a cow, kept four days in strong sulphuric acid, exposed more or less to the air. The primary bundles have become much broader, and the extremities are mostly cut off into sharp rectangles. On some places of the surface where the muscular bundle is narrower, we see dark transverse lines. It would appear, that the swollen contents of the primary bundles is here prevented from expanding itself, owing to the restraining resistance of the sarcolemma. In other places the primary bundles have been transversely cut through. The transverse lines are still visible, on some places the longitudinal fibres are very distinct; the kernels are swollen, and here and there they have become granular. In one bundle we see two rows of the elongated and swollen kernels, placed at small and regular distances from each other.

The addition of water produces no change. Hence it would appear that water has been absorbed from the air, which has prevented the sulpho-proteic acid from becoming fully gelatinous.

The muscle of a cow. Strong nitric acid causes a powerful disengagement of gas, and makes the primary fibres, which were formerly very distinct, disappear. The little bundles, however, still distinctly exhibit their boundary lines, which seems to show that the sarcolemma is not affected. Nitric acid, diluted with its own bulk of water, produces the same effect. A mixture of one part of nitric acid and four parts of water, leaves the primary fibres still distinctly visible; but after some time the transverse lines, and subsequently the primary fibres also disappear, the whole bundle becoming more transparent. Here and there elongated kernels present themselves; the sarcolemma appears without any distinct structure, although it shows alternating dark lines on several places.

The muscle of a frog, after being kept in caustic ammonia for four days, in a covered watch-glass. The primary bundles have become more transparent; the primary fibres are not distinct; the kernels are transparent and have become somewhat broader; the transverse lines are everywhere very distinct. A large quantity of a powdery substance, which exhibits no structure under the microscope, has been deposited in the liquid.

which the pearls are placed at small mutual distances, and arranged on a thick thread.

So far as we are at present acquainted with the nature of these substances, I should be inclined to consider the one as fibrin, and the other as binoxide of protein. When, for example, muscles, that have been previously washed with water, are treated with acetic acid, these primary fibres are dissolved, and if carbonate of ammonia is then added to the liquid, the precipitate obtained is binoxide of protein. Now this is a property which fibrin exhibits, when treated in the same manner, and also binoxide of protein under certain conditions. The organic difference of the fibre indicates to us the existence of two

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The muscle of a cow. By the action of a strong solution of potash, the bundles of muscles become somewhat more transparent; both the transverse lines and the primary fibres remain distinct. The kernels are easily distinguished. After the substance has been left upon the object-holder for 48 hours, everything remains the same, except that the kernels appear broader and more distinct; the primary fibres and transverse lines are also very well visible.

The muscle of a frog, having been kept five hours in strong potash ley. The primary bundles (fig. 160, *a*) are easily isolated, and very soft, granular, and but partially transparent. The primary fibres are distinctly visible, but in some of them no transverse lines appear. The most important change has been effected in the kernels (1), as they are very much swollen, have become elliptical, and exhibit a granular appearance. On the addition of water, everything is soon dissolved. When the water first reaches them, the kernels swell into almost perfect spheres, (fig. 160, *b*, 1) after which they disappear. Sometimes the transverse lines reappear when nearly the whole is dissolved.

The muscle of a frog which has been kept twenty-four hours in strong potash. The primary bundles are mostly isolated, or may easily be separated from each other, and are divisible both in the longitudinal and transverse direction. The greater part of them are divided into transverse pieces, cut off at right angles (fig. 161, 1). The transverse lines are still quite visible, and the primary fibres show crenulated edges. They have the appearance of little pearl necklaces (2), and therefore appear to consist of heterogeneous parts, which give rise to these transverse lines. One part seems to be more soluble in potash than another, which has the effect of rendering the bundles easily divisible in the direction of the transverse lines. On the addition of water everything is dissolved.

The muscle of an almost full-grown fœtus, kept in strong potash for half an hour. It has become very soft; the primary bundles are easily isolated, their edges are mostly smooth, but sometimes crenulated. On some places the traces of transverse lines are still left. Primary fibres cannot be seen. The kernels are situated at long distances from each other. They are swollen, but not distinctly marked, and often were hardly distinguishable. No other ele-

distinct substances; and it happens, that fibrin and binoxide of protein are two substances, which we know to exhibit reactions corresponding to those of the primary muscular fibres, which we have just mentioned.

This organic variety of every primary fibre has the effect of making every bundle formed from them present transverse lines, arising from the exact and regular juxtaposition of the homogeneous granules of the fibres of the whole little bundle, thus causing the appearance on the surface of a series of lines placed at right angles upon the bundle. Now, as the thinner globules which are placed between those that are thicker, and which serve to hold them together, are more soluble in various liquids than the others, the primary bundles of the muscles may by these means be divided in two directions, viz., in a longitudinal direction into fibres, and in the transverse direction into discs. This is a peculiarity which has been represented

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mentary forms are to be seen but the primary bundles, which lie distant from one another.

On the first action of water the primary bundles become paler, without, however, any distinct swelling. The kernels become expanded, and some of them disappear, whilst the outlines of the primary bundles still remain almost unaltered. After the water has acted for some time longer, nothing is left of the muscular bundles except some few fine granules. Now, also, the smaller blood vessels, and even the capillary vessels still filled with blood corpuscles of a yellow colour, appear quite distinctly. On the addition of more water, the muscular bundles are entirely dissolved.

The muscle of a cow, which had been kept twenty-four hours in strong alcohol. The longitudinal fibres are now very distinct, and the transverse lines also. The isolated primary fibres are granular.

The muscle of a cow. On the addition of corrosive sublimate the outlines of the primary bundles appear distinctly. The isolated primary fibres appear to consist of small elongated particles, bordering each other. They present small and irregular swellings.

After having been kept for eight hours in this solution, the primary bundles have become hard, untransparent, and easily separable from each other. The transverse lines are very distinct, but the primary fibres in the bundle cannot be properly distinguished; the kernels are very narrow.

The muscle of a cow, after having been kept in tincture of iodine for forty-eight hours. Both the primary bundles and the perimysium are coloured intensely brown. The isolated primary fibres present themselves as regularly arranged granules; a few lying next each other and separated from the bundle, still present transverse lines. They have all a deep brown colour. (Donders and Mulder.)

by Todd and Bowman (see Physiological Anatomy and Physiology of Man, i. p. 152, 1) nearly in the same manner as our observations have shown it to us, although we did not perceive the transverse division as distinctly as they did.

These muscular fibres are encased in a tube consisting of a tissue which does not belong to the gelatinous class, but appears from its properties to be an intimate mixture of the substances that constitute the gelatinous and elastic tissues, and which appears to contain some kernels, which are rendered distinctly visible by acetic acid, and swell under the action of potash.

These two forms, viz., the primary fibres and the little enclosing tubes, give their characteristic peculiarity to the voluntary muscular tissue. A third substance, however, which deserves to be distinguished, is found in addition to these. This substance is a shapeless intermediate matter, separating those primary fibres from one another which do not lie in direct contact.

The secondary bundles are mutually united by threads of ligamentary tissue, which, in a few cases, contain fat cells; the whole mass of muscles is further interwoven with vessels and nerves.

Besides these voluntary muscles two other kinds have been distinguished. First, muscular fibres, which have the properties of the fibres of ligamentary tissue, and are present in the iris and the coats of the lymphatic vessels; these react from galvanic stimulation. Secondly, there are muscular fibres, agreeing with those of the intermediate coat of the arteries; these are found in the muscular coat of the stomach and intestines. They are both called *involuntary* muscles.

As regards the former, viz., those resembling fibres of ligamentary tissue, they cannot yet with certainty be classed with these fibres. We are even induced to doubt the conclusion regarding their nature, which has been derived from their form, for they (viz., the fibres of the iris) have the same chemical character as muscular fibres. According to Henle, their form is exactly the same as that of ligamentary

tissue. Valentin, however, finds these fibres similar to non-striated muscular fibres, interwoven with ligamentary tissue. Further investigations on this subject, therefore, are yet required.

Those of the second kind, which are similar to the muscular fibres of the intermediate coat of the arteries, and are called *smooth simple* fibres, consist of oblong and narrow plates (fig. 164, *a*), tapering a little towards the extremities, and containing here and there oblong kernels, sometimes a row of little points, arranged in one straight line over the whole length. They are found in the alimentary canal, the bladder, and in various other places, where the muscular motion is known to be involuntary; and also in the muscular coat of the arteries, (fig. 171, *a*). They are soluble in acetic acid. These muscular fibres have been regarded as of an entirely peculiar character, first, because their form resembles that of some fibres of the intermediate coat of the arteries, and also because other fibres of this intermediate coat were found to be of a peculiar nature, totally different from that of muscular fibre. It should be remembered, however, that in this coat of the arteries there are two kinds of threads, viz., those of elastic tissue and of involuntary muscles; and therefore no certain conclusions can be drawn regarding them, if the entirely different nature of these two kinds of fibres be lost sight of.

All that we know of the fibres of the involuntary muscles is, that they are arranged together into small bundles, these bundles not being incased in one common tube, like those of the muscles which are subject to the will. These fibres themselves,—that is, the primary fibres,—are flat and thin. We find among them, first, thin threads of elastic tissue (figs. 162, 163, and 164, *c* 2); these are distinguished by Henle by the name of kernel-fibres. They must be considered as thin elongations of the primary kernels, which, if more fully developed, would produce true threads of elastic tissue.

The muscular fibre properly consists of a substance which is soluble both in potash and acetic acid, and which becomes yellow by the subsequent action of nitric acid and ammonia,

indicating that it is a protein compound. To what class of these compounds it belongs, however, is not known. The involuntary muscles differ in respect of the homogeneity of their structure from the voluntary muscles, in the latter of which, two substances that are chemically different can be distinguished.*

It is therefore only for a technical (practical) purpose, that the knowledge of the chemical composition of the muscles, as such, can be useful. They have, in this respect, been examined by Berzelius with great care many years ago.

The muscles contain, when saturated with blood and nutritive liquid, 77 per cent. of water, and 5 per cent. of substances soluble in cold water. In 100 parts of muscle, therefore, there is contained 18 per cent. of substances insoluble in

* *Involuntary muscular fibres, taken from the œsophagus of a cow* some hours after death. It presents itself as thin, straight fibres. By the action of acetic acid they become very transparent, and present a great number of elongated kernels. Some of them swell very much, and become oblong and granular.

After having been kept in strong potash ley for one or two days (in a closed bottle), it appears finely granular and shapeless. After the addition of water, this granular matter disappears, and very thin little threads, with sharp outlines, make their appearance. These threads sometimes ramify and unite with one another (fig. 162). They are to be considered as kernel fibres or elastic fibres.

After being kept in a solution of corrosive sublimate for two days, they have become granular.

In tannic acid, for the same period, un-transparent.

In sulphuric acid, left for two days, they have swollen into a jelly. The thin elastic fibres, running vermicularly, are seen indistinctly through them.

The muscular fibres of the intermediate coat of the arteries, after having been kept in potash for four hours, have become broad, flat, and transparent, but not granular. The elastic tissue of the arteries has retained its form, even after the potash has acted upon it for twenty-four hours, but the fibres can now be more readily separated from one another. The fibres are thinner than those of the cervical ligament, but they both present the same reactions. Thus it appears, that there is a definite difference between the elastic and the so-called involuntary muscular fibres of the arteries.

The latter, when not treated with any reagent, have the appearance of flat, pure, transparent, fibres.

Muscular fibres of the circular, fibrous coat of the arteries, having been kept in potash for some hours, have become swollen and somewhat granular. By the addition of water, nearly the whole is dissolved, with the exception of fine fibres, with sharp outlines and running in a vermicular direction.

Involuntary muscular fibres, taken from the thick intestines of a full-grown

cold water, which become hard by boiling, and, besides the coats of the vessels, a little fat, &c., produce chiefly bi-oxide of protein, which is much more difficultly soluble in acids than the muscular fibres themselves, and hence must be difficultly digestible.

When the muscles are cut into small pieces, kneaded with cold water, and afterwards treated with boiling water, a portion is dissolved out, which is partly tri-oxide of protein, derived from the primary fibres, and partly gelatine from the ligamentary tissue. When muscle is boiled, without being previously minced and kneaded with cold water, we obtain, besides bi-oxide of protein, also coagulated albumen from the serum, which has been left in the mass as an insoluble substance; the decoction contains gelatine from the ligamentary tissue, tri-oxide of protein from the boiled muscular fibre, and from the fibrin and albumen of the blood, and a number of other

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man. They appear as thin, flat, transparent threads (fig. 161, *a*), when examined separately; and in masses they present a rough surface (*b*). After the action of acetic acid (*c*) they become much paler, do not swell much, but present a great number of elongated kernels (1), and in a few places, some thin, elastic fibres (2). By the action of nitric acid, succeeded by ammonia, they become yellow. Those of the inferior half of the *œsophagus* are more distinct, flat, and likewise transparent. Here also the action of acetic acid causes the appearance of a number of kernels and kernel fibres.

Involuntary muscular fibres, taken from the intestines of a frog. The threads, after having been in strong acetic acid for some hours, are perfectly transparent, finely granular, and present a few small granular protruding bodies.

The bundle of fibres, after having been kept for some hours in a solution of tannic acid, has become untransparent and rough on the surface; the fibres have also become rough, but remain transparent. On the surface of the bundle a great quantity of granular particles are visible.

By the action of a solution of corrosive sublimate, continued for some hours, the bundles become of a dark appearance, granular, and are with difficulty divided into their primary fibres.

After having been kept in alcohol for a number of hours, the primary fibres have become somewhat hairy on the edges, and transparent. The appearance of the bundles is granular. No sarcolemma is to be seen.

By the action of strong sulphuric acid continued for some hours, the bundle becomes very gelatinous, transparent, and is still more or less fibrous. On the addition of water, it contracts, becomes opaque, fibrous, and granular, all but homogeneous. When potash ley is subsequently added, and the sulphate of potash that is produced washed out, there remains a finely granular, fibrous substance. (Donders and Mulder.)

substances besides, which are derived partly from the arterial and venous blood that exists in the muscle, partly from the fluid of the serum vessels, partly from the nerves, and partly from the gelatinous and fatty tissues.

A cold aqueous solution of flesh, therefore, contains albumen which coagulates by heat; and besides, organic salts, partly soluble in alcohol, viz., salts of potash, soda, lime, magnesia, ammonia, the chlorides of calcium, sodium, and potassium. Mixed with these are the carbonates of potash and soda, and phosphate of lime, which has been rendered soluble in alcohol by the agency of extractive matters. The greater part of the phosphates of soda and lime remains insoluble in alcohol.

The alcohol dissolves a number of extractive matters, which are described collectively under the name of osmazome. What is known by this name is simply a mixture of various substances which have been browned during evaporation, and of which it is difficult to trace the origin. Part of these belong to the fibrin of the blood; for when fibrin is boiled in water, and, after the water has been evaporated, the remainder is treated with alcohol, the latter takes up a red coloured extract. Part of these matters, however, may also have been present in the blood, another part in the nerves, and another may have been formed from the substances which have undergone change during the evaporation. Lastly, the alcoholic extractive matters contain fats derived from the muscular mass, and fatty salts from the blood with which the muscles were saturated.

By digesting the watery extract with absolute alcohol, extractive substances are dissolved out, similar to those present in the extract of urine. These substances are constituents of the blood, which leave the organism through the kidneys. By corrosive sublimate one part of them is precipitated; by basic acetate of lead another, and a third part is left in solution.

From the portion that is left insoluble, alcohol extracts a yellow substance of 0.833 specific gravity. In this extract, when dissolved, a copious precipitate is produced by infusion

of galls and by corrosive sublimate, but none by neutral acetate of lead or chloride of tin.

The part insoluble in alcohol of 0.833 specific gravity is a dark brown extract, one part of which may be precipitated by corrosive sublimate, another by chloride of tin, and in which several other extractive matters still remain. (See Berzelius, Chemie, IX. p. 575.)

From the alcoholic extract of beef tea, previously evaporated to dryness, Chevreul obtained another crystallisable substance, which he called *kreatin*. This substance is destitute of smell or taste. It has also been found by Woehler, but has not been further examined.

The real elementary main constituent of the muscles, viz., that of their primary fibres, is but imperfectly known. It is, however, probable, that it agrees with fibrin in containing bi-oxide of protein. As regards the substance which lies between these primary fibres, nothing can yet be said with certainty. Like the fibres, it has the character of a protein compound; and possesses the chemical properties characteristic of such compounds. It is soluble in acetic acid, becomes gelatinous and transparent in dilute acetic acid, &c. The statement made by Ficinus, that the primary fibres are hardened by alkaline carbonates, is certainly incorrect. Bouchardat mentions* that they are affected by dilute hydrochloric acid in the same manner as fibrin; they are rendered gelatinous at the ordinary temperature, and are subsequently dissolved.

The red colour of the muscles is due entirely to the blood which exists in their capillary system. When injected with water, every muscle is colourless. They contain no peculiar colouring matter; nor, as has been thought, any except that found in the capillary system. When injected with oil, the muscles of living animals exhibit only a yellowish colour. After the death of the animal, this experiment did not completely succeed, as the blood, which was then coagulated, could not in this manner be entirely removed. The blood is the only cause of the red colour.†

* Scheikundige Onderzoekingen, Deel II., p. 578.

† A. Luijten. De musculorum rubore. Dissertatio inauguralis, 1840.

Any determination of the composition of muscle by ultimate analysis may be called unattainable; for in this process we burn a mixture of various substances, a very complicated tissue of muscular fibres, ligamentary tissue, coats of blood vessels and nerves. If, therefore, Playfair and Böckmann* have found the composition of muscle to be identical with that of blood,—which is a mixture of various substances, containing some that are entirely different from those of muscle, and in which again others are wanting that are present in the latter,—then this may be considered as a proof that it is impossible to find out essential differences by means of ultimate analysis.

The analyses just mentioned, have, however, been repeated by Adriani, and the results obtained by him represent the composition of muscle as somewhat different. When either dissolved in a weak potash ley, and precipitated by acetic acid, or dissolved in this acid and thrown down by carbonate of ammonia, as in preparing protein, he found the proportions of its constituents to be about the same as those existing in bi-oxide of protein, viz., $C^{40}\ H^{31}\ N^{5}\ O^{14}$.† Fibrin,

* Liebig, Phys. Chem. 2d Aufl. S. 290.

	Beef.		Ox blood.	
C	54.12	54.18	54.19	54.20
H	7.89	7.93	7.48	7.65
N	15.67	15.71	15,72	15.73
O	22.32	22.18	22.31	22.12

† Muscular flesh, extracted with cold water, alcohol, and ether, dissolved in acetic acid, filtered and precipitated from the solution by carbonate of ammonia, yielded:—

	Found.	Atoms.	Calculated.
C	53.91	40	53.36
H	7.15	31	6.75
N	15.24	5	15.45
O + S	23.70	14	24.44

When dissolved in caustic potash, one part to 40 of water, filtered and precipitated by acetic acid, washed with water and digested with alcohol and ether, it yielded—

C	53.83
H	7.11
N	15.38
O	23.68

treated in the same manner, gave the same result. It readily absorbs oxygen from the atmosphere.*

Muscle, when submitted as a whole to ultimate analysis, produces, according to Adriani's experiments, a result approaching to the composition of a protein compound; but which can be of no value as such, owing to the quantity of gelatinous tissue, coats of arteries, veins, lymphatic vessels, capillary vessels and nerves, with which the muscular tissue is mixed.† Such experiments prove too much, and, therefore, nothing at all.

They have, however, given results, essentially different from those obtained by Playfair and Böckmann; and from the nature of the muscles, it is also evident, that the results obtained by the two latter cannot possibly be accurate; for when muscles are analysed in a mass they must yield a smaller

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The results of these experiments prove distinctly that the produce is chiefly bi-oxide of protein, and not merely protein; and it is for this reason, especially on account of the last-mentioned result, that I cannot think that the primary fibres of the muscles consist of protein. But it is difficult to decide which of the two distinct substances that can be distinguished in the primary fibres, is the bi-oxide of protein, viz., whether the thick globules or the thinner parts between them. From the somewhat large proportion of carbon in the two substances, it seems to follow that another protein compound containing less oxygen is mixed with the former.

Although we must leave still undecided the composition of the substance found between the primary fibres, I am of opinion that it may be assumed as certain, that fibrin is not the only substance existing in muscle, and that in no case should the primary fibre be called fibrin.

* Scheikundige Onderzoekingen. Deel I. p. 568.

† Scheikundige Onderzoekingen. Deel III. The muscular flesh of a cow, taken from the midst of the muscular mass, cut into very small pieces, kneaded with cold water, and then digested with warm water, alcohol, and ether, yielded—

C	53.34	52.92
H	7.23	7.30
N	16.31	
O	22.71	
S	0.41	

It contained no free phosphorus, but a quantity of sulphur, which was about equal to that found in fibrin.

Schlossberger has analysed the flesh of different animals (Berzelius Jahresbericht, 1843, S. 607). In that of fishes and lobsters he found no blood-corpuscles, but in the latter he discovered a kind of colouring matter, which was

proportion of carbon than otherwise, because they then contain a considerable quantity of gelatinous tissue, which, on analysis, yields only 50.37 per cent. of carbon. It appears that in the experiments of Playfair and Böckmann, the determination of the hydrogen is totally incorrect. The proportion of nitrogen must be greater than they have found it, because gelatine contains 18 per cent. of nitrogen.

Nothing, accordingly, has ever surprised me more than the assertions now so frequently repeated, that muscles and blood are identical in composition—two substances which present, in fact, no other points of resemblance except this, that they both contain protein compounds. But if we proceeded upon this principle, we should be induced at present to apply the term identity to a great number of substances indeed.

OO. Blood Vessels.

In the higher classes of animals there exist two kinds of tubes, conveying blood, viz., arteries and veins. Between these we find, on the one hand, the heart, on the other, the so-called capillary system, which unites the two. The

similar to fat or resin. In older individuals the proportion of water decreases, and that of fibrin and blood-corpuscles increases in the same ratio.

	Beef.	Veal.		Pork.	Deer.	Pigeon.	Chicken	Carp.	Trout.
Fibrin, ligamentary tissue, &c.	17.50	15.00	16.2	16 8	18.	17.	16.5	12.	11.1
Uncoagulated albumen, and cruor	2.2	3.2	2.6	2.4	2.3	4.5	3.0	5 2	4.4
Alcoholic extract with salts	1.5	1.1	1.1	1.7	2.4	1.0	1.4	1.0	1.6
Watery extract with salts	1.3	1.0	1.6	0.8		1.5	1.2	1.7	0.2
Bone earth with animal matter		0.1			0.4		0.6		2.2
Water and loss	77.5	79.7	78.3	78.3	76.9	76.0	77.3	80.1	80 5

In insects the muscular bundles are found free from ligamentary tissue, and therefore, these little animals afford a fine opportunity to obtain from the muscles of the skin bundles of pure muscles for examination. These bundles appear to be in every respect similar to those of other animals, but their transverse lines are a little more distinct, and they contain far thicker primary fibres, in which the globules formerly described may be distinctly seen.

vascular system, therefore, is a continuous canal, constituted in this manner: first, the heart, then the arteries, capillary system, veins, and at last the heart again. The two kinds of blood-conveying tubes, which are called arteries and veins, may now be treated of briefly, in a physiologico-chemical point of view, because they present only a collection of elementary forms, which have already been under consideration. The coats of the arteries consist, commencing from within, first of simply laminated epithelium (fig. 172), (see p. 497), being a thin layer of cells with kernels, as indicated in the description of the peritoneum and elsewhere. The second coat is called striated or fenestrated vascular membrane, and consists of several layers of fibres (fig. 170 and 165, 5), which are situated at some distance from each other within a membrane, most frequently arranged in a longitudinal direction, and mutually connected by a great number of ramifications. The third coat consists of a great number of plates, formed of densely packed, strong, and elastic longitudinal fibres (fig. 165, 3; 166, 1; 167, 1; and 169); and between these plates muscular fibres are very intimately interwoven (fig. 171, *a*). This is called the fibro-muscular coat. The fourth, called the elastic coat (fig. 165, 2), consists of longitudinal elastic fibres, and is covered by a fifth, the adventitious coat (fig. 165, 1).

The chief constituent of the second, third, fourth, and fifth coats is elastic tissue. In the adventitious coat this is interwoven with a very great number of threads of gelatinous tissue; and this is also the case, but in a less degree, in the elastic coat; whilst the fibrous circular coat contains threads and plates of elastic tissue, involuntary muscular fibres, and perhaps, a few threads of gelatinous tissue. The striated coat consists of elastic tissue only.

The composition of the coats of the arteries, therefore, is simply this: elastic tissue, in the form of threads of various thickness, and running in various directions; threads of gelatinous tissue, and involuntary muscular fibres, intermixed with nerves and capillary vessels.

Scheerer, who has analysed the middle coat, employed in

his analysis a mixture of elastic and muscular tissue (including nerves and capillary vessels). Ann. der Pharmacie. Bd. 40.*

The veins do not contain any involuntary muscular fibres, but in other respects, the coats of which they consist are es-

* *The human aorta.*

A transverse section examined after previous drying and subsequent soaking in water (fig. 165, 166, and 167). By the action of acetic acid the adventitious tunic becomes transparent (fig. 165, 1), with the exception of a few, thin elastic fibres gradually passing into the elastic tunic (2), which leaves more and thicker elastic fibres behind (fig. 168). The fibrous circular tunic, which follows next (fig. 165, 3), retains a much darker appearance, and its fibres are much less detached from one another. This tunic consists of a great number of little plates, running parallel, and placed at tolerably regular distances from one another (fig. 166, 1, and 167, 1), and severally appearing as an intertexture of transparent elastic fibres, interwoven in every direction (fig. 169), and of which the innermost leave no interstices between them. Between these plates occur the muscular fibres with their elastic fibres, (fig. 166, 2, and 167, 2). The longitudinal fibrous tunic is more granular (fig. 165, 4), owing to the transverse cutting of the muscular fibres. The striated tunic (fig. 165, 5), exhibits a number of parallel lines; when the plates of which it is composed are detached from each other, fine fibres become visible, which do not disappear in acetic acid (comp. fig. 170). After this follows the epithelium.

After the action of potash and water had lasted for six hours, not only the elastic fibres, but also the adventitious and elastic tunics were dissolved; but in the fibrous circular tunic, the tissue, occurring between the elastic plates, still appears fibrous. The striated tunic becomes detached from the remaining mass in the form of transparent and coherent fibres.

The transverse section *of the aorta of a cow* also presents throughout elastic fibres, after being treated with potash and water.

The breadth and thickness of the fibres of the several tunics is different; those of the fibrous circular tunic being the thickest. The epithelium gives way and appears suspended in the liquid in the form of little plates.

The carotid artery of a cow.

The fibrous circular tunic (between the elastic plates), recently prepared, presents on its surface fibres of elastic tissue, at more or less regular distances from each other, and having mutual ramifications. Between these ramifications there are situated flat and broad fibres, not sharply defined and but indistinctly visible. By acetic acid the whole, with the exception of the elastic fibres, is rendered transparent to as great an extent as in the involuntary muscular bundles, but much less than in the ligamentary tissue. Here and there we perceive the boundaries of the less distinct fibres, mentioned before, without any elastic fibres placed between them, the latter having apparently no immediate connexion with the involuntary muscular fibres of this tunic. We only see everywhere small portions of the elastic fibres, which are situated at a greater depth, shining faintly through. The fibres of the involuntary

sentially similar to those of the arteries. They are formed of plates, consisting of agglomerated threads of elastic tissue (fig. 176, *a*, *b*, *c*, and *d*, and fig. 178), with threads of gelatinous tissue (fig. 177).

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muscle, after having been treated with strong potash for seven hours, present themselves separated from one another, and appear to consist of a transparent thread, with uneven edges and a great number of minute granules, diffused through the substance. Two different substances, therefore, are present here. On the addition of water, the transparent substance is first dissolved; the granular matter resists longest, but is at last also dissolved in the weak ley. The elastic fibres are left behind unaltered.

The *striated tunic* (fig. 170), also recently prepared in water, when seen from the side of the epithelium, presents a large number of thin fibres, placed closely together, running nearly parallel and uniting together at acute angles, without any distinct particles appearing between them. The fibres extend themselves in the longitudinal direction of the artery, upon which the muscular fibres of the fibrous circular tunic are placed at right angles. The fibres of the striated tunic appear to cohere by means of a membrane. Acetic acid renders the whole more transparent, but leaves the fibres unchanged. If this tunic is stretched out, the edges curl much. After having been kept in potash for seven hours, it is unaltered, and still remains so after the addition of water, and the membrane, in which the fibres are contained, is likewise unchanged. The latter, therefore, probably consists also of elastic tissue.

The *elastic tunic* consists of elastic fibres (comp. fig. 168), forming meshes which have their longest dimension placed in the longitudinal direction of the arteries.

The longitudinal fibrous tunic was not present here.

A transverse section, after having been kept for four hours in a strong potash ley, with the subsequent addition of a little water. In the elastic tunic we see the section of the longitudinal elastic fibres, which constitute a number of concentric layers round the artery, and are placed in close mutual contact. When one of these plates falls back, the net of the elastic fibres with narrow meshes becomes visible. The fibrous circular tunic has lost its muscular fibres, and presents long fibres (plates) of elastic tissue.

The striated tunic appears as a dark and tolerably broad rim of transversely cut elastic fibres.

The elastic fibres, therefore, run longitudinally in the elastic tunic; towards the outside they gradually pass into the fine elastic fibres of the adventitious tunic; towards the inside they cohere with those of the fibrous tunic. In the latter we find a few elastic plates of greater breadth, the outermost of which consist of fibres with small meshes, whilst the innermost are real coherent plates, in which but minute apertures are left. Between these plates there are large spaces, in which circular involuntary muscular fibres, with thin elastic fibres, are placed. The fibres of the striated tunic run principally in a longitudinal direction. After the action of potash, the latter tunic is readily loosened.

The threads of these two elementary forms alternate with each other, and their relative quantities differ, so that the elastic fibres towards the centre of the vessel (fig. 173, *a*, 2, and 174, *a*, 2), although thinner, are in greater number, whilst towards the circumference they become thicker and more alternating with threads of ligamentary tissue (fig. 173 and 174, *b* 2).*

The fibres of some threads, taken from the middle tunic of the large artery of a sheep, (fig. 171, *a*), become transparent by the action of acetic acid (*b*), but only in a degree similar to those of involuntary muscle, and within them are to be seen a large number of kernels, regularly diffused through the whole, with minute elastic fibres.

The *internal carotid* of a sheep, placed in acetic acid, has the same appearance as the before-mentioned carotid. In the adventitious tunic thin elastic fibres occur, with a great number of fibres of conjunctive tissue. The elastic tunic consists of closely packed plates of elastic fibres, six to seven in number, which separate but little from one another, showing that they contain but few fibres of conjunctive tissue. The circular tunic consists of involuntary muscular fibres, between which there are thin elastic fibres, whilst we perceive plates of elastic fibres placed at regular distances. The striated tunic consists of a series of plates, composed of fine fibres of elastic tissue.

The *intercostal artery* of a sheep, cut through transversely, presents the same tunics as the large arteries before-mentioned.

The *coeliac artery of a man* has the same general characters, but the elastic fibres have a less laminar appearance, having greater similarity to threads.

When a transverse section of the *dried aorta* is heated with strong nitric acid, and then moistened with an excess of ammonia, part of the tunics become dark yellow, the others remaining colourless. But it cannot be correctly determined which tunics become yellow—and therefore contain muscular fibres,—and which remain colourless. It is certain, however, that the fibrous circular tunic is one of those that become yellow. (Donders and Mulder.)

* The *sub-clavian vein of a cow*, the longitudinal section, dried. When placed in water, it presents some layers of elastic fibres, alternating with others which run in the longitudinal direction of the vein (comp. fig. 173, *a*). On a transverse section these layers are also visible, and the elastic fibres appear cut through transversely (comp. fig. 174, *a*, and 175). After being treated with acetic acid, the elastic fibres in the outermost layers (fig. 174, *a*, 1, and 176, *a*), appear as broad as those in the elastic tunic of the arteries. Towards the interior these elastic fibres are thinner (fig. 174, *a*, 2), and assume more and more the appearance of elastic plates (fig. 176, *b*, *c*, and *d*). The bundles that are placed between (fig. 173, *b*, and 174, *b*), have become very much swollen by the action of the acetic acid, and consist of ligamentary tissue (fig. 177), by which the layers of elastic tissue are separated from each other. The distance between these several layers becomes far less towards the interior surface of

The capillary system demands our peculiar attention; for it is there that the arterial blood becomes venous, and as the blood supplies the materials by which the several parts of the body are nourished, this capillary system is the place where the most important transformations of the blood are performed. From the blood contained in this system, the adjoining simple particles of the organism take what they want for their nourishment and support.

It must not, however, be imagined, that the capillary system itself is the place of action, or that the walls of the capillary vessels exercise any influence upon the change of materials. It would appear, on the contrary, that the capillary system serves no other purpose than to convey the nourishing fluid to and from the several elementary forms, which are interwoven through this system. The point where chemical action commences is *without*, and not within the capillary system. It is, nevertheless, of the highest importance to the life of the animal, and to all its functions, because this set of fine tubes enables the animal organism to accomplish a very complicated change of materials, for which the

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the vein (fig. 173, *b*, 1, and 174, *b*, 1); consequently the threads of ligamentary tissue between the elastic plates are here less in number.

The broad elastic fibres are here and there in the innermost tunics so tightly interwoven with one another, that they may rather be said to constitute a plate with minute holes (fig. 176, *d*), than to have retained the fibrous form.

Between the layers of the elastic fibres we find threads of ligamentary tissue arranged in layers. Hence the veins consist of layers both of threads and of plates of elastic tissue,—of which the latter are situated towards the interior of the vein,—and layers of threads of ligamentary tissue. No involuntary muscular fibres have been perceived. By acetic acid the fibres between the elastic layers become suddenly swollen and transparent. The little fibres of the striated tunic, after being treated with potash for sixteen hours and a subsequent addition of water, have a somewhat swollen appearance (fig. 178). The ligamentary tissue is dissolved, but the elastic fibres and plates are left unaltered.

On the edge of a *valvule* of the same vein, coloured with tincture of iodine, we perceive a colourless and transparent rim, which is the epithelium.

Another valvule, when treated with acetic acid, becomes immediately very transparent, and the threads of ligamentary tissue disappear from it. Only a few elastic fibres present themselves, and they are here very thin. In a mixture of potash ley and water, the valvule is readily dissolved; only a few fibres are left. (Donders and Mulder.)

vegetable organism is unfit. These tubes, however, cannot produce the substances, which give rise beyond the capillary system to the existence of such very different elementary forms.

The capillary system is a set of closed, fine tubes, commencing at the extremities of the arteries, and ending at the commencement of the veins. By means of this system, the arteries and veins have an uninterrupted communication with each other, although this takes place through exceedingly narrow tubes. We learn from this, that although the conversion of arterial into venous blood takes place *within* the capillary system, it is not effected through it. The tubes proceed without interruption, as appears, among other things, from this, that the blood corpuscles, although elongated and changed in form in these narrow tubes, are, however, again of the same form, when returning through the veins, as when they were carried on through the arteries. The capillary system is a fine network of little vessels, which undergo no further division, giving off no finer ramifications, but mutually communicating in various ways.

Such a system of little vessels is found in all the organs which do not belong to the tissues of epithelium, enumerated at page 495.

There are some tissues, however,—such as the tendons, the ligaments, the cartilages—which are only externally, that is round their secondary bundles, surrounded by it, and thus receive no nourishing fluid, except at very great distances Every other organ receives one or more arteries, and one or more veins leave these several organs again. These form for themselves a common capillary system, however different the tissues may be of which an organ consists. As the minute ramifications of the capillary vessels cross each other in every direction, and exist in large numbers, they are brought by this arrangement into the very closest neighbourhood of the elementary parts of each tissue, although with most of these parts they are in no direct communication. For this purpose they are too wide, compared with the primary fibres of primary globules, except in the case of the fatty and glandular

cells, which have been observed to be in direct communication with the capillary vessels. In several organs a bundle of primary fibres is, as it were, enveloped in capillary vessels, as we find in the muscles. The glandular tubes are in the same way enclosed within a little vascular network (Henle, p. 475).

The velocity with which the blood flows through the capillary system, is not the same in every portion of it. In the first place, this velocity is greatly influenced by the greater or less division of the arteries, and the greater or smaller number of the communicating branches (anastomoses), previous to their passing into the capillary vessels. In the lungs we often see such a transition take place suddenly, and thus the blood could circulate in them with a proportionably increased velocity, if the canals of the capillary vessels were not here so very minute. Moreover, the passage of the blood through the capillary vessels is very different in different organs. The wider these vessels are, the more rapid is the circulation of the blood, all other things being equal.

It is clear, that this greater or smaller degree of velocity, with which the blood flows through the capillary system, must have an important influence upon the change of the materials which, after having passed through their walls, are converted into the elementary parts of the body. In some organs, of which the capillary vessels are so narrow that they scarcely allow the blood corpuscles to pass through them, the latter must be arrested for a long time; and here this slower motion of the blood may have a powerful influence upon the adjoining particles of the tissues, from which the nutritive liquid is separated only by the thin walls of the capillary vessels. A consequence of this must also be, that this nutritive liquid leaves and returns to the capillary system with a correspondingly increased energy. In the lungs these vessels are, according to Valentin's measurement, very narrow, and, although in a certain time a great quantity of blood flows through the very numerous ramifications of the capillary system in this organ, yet the blood passes but slowly through each separate capillary vessel; and it is not there-

fore necessary that we should represent the taking up of oxygen and the giving off of carbonic acid through these vascular coats as taking place in a short period of time.

The very smallest capillary vessels have in all organs neither the same direction nor width, nor are they equally numerous. We perceive in their walls not a trace of fibres, or any other distinguishable particle; nothing else can be seen but a little hollow cylinder, consisting of walls, which are devoid of any structure, and are insoluble in acetic acid. There is every reason to suppose that bi-oxide of protein, although not the only, is yet among the chief constituents of the capillary vessels, but our knowledge of this is still limited. Here and there, however, we find minute bodies, placed either in or on the outside of the wall, having the size of cell kernels, and resembling these also in their containing nucleoli. They are therefore assumed to be cell-kernels. In capillary vessels of a somewhat larger size, a great number of these cell-kernels may be distinguished, lying on the outside of the wall, and in addition to these are perceived other oblong little bodies, placed either longitudinally or transversely, and of various forms.

The capillary vessels are devoid of any visible external apertures. The blood, therefore, that leaves and that enters it, must do so by exosmotic and endosmotic action.

The constituents of the blood, that exude through the walls of the capillary system, will be considered when we treat of the secretions. This entering and leaving the capillary system by the constituents of the blood, is the origin of the difference between arterial and venous blood.

PP. Lymphatic and Chyle-vessels.

There are some vessels, which, like the veins, originate from a peculiar capillary system; they are called lymphatic vessels. They are similar to the veins in their continually enlarging in size by the joining or anastomosis of a number of smaller stems. These vessels are for the greater part in connexion with the thoracic duct, which in the human body discharges itself into the left sub-maxillary vein. These

lymphatic vessels constitute one system along with the milk vessels, which originate from the chylic and pass into the thoracic duct.

Both these kinds of vessels draw their origin from a peculiar capillary system; the latter convey the chyle or some of the substances absorbed from the intestines, whilst the former contain a liquid which has been carried through the arteries into the capillary system, and after having penetrated through the walls of the latter, has been used to effect a change of materials. The largest portion of the fluids that have passed outside the walls of the capillary system is carried back into the circulating blood, not by the veins, but for the most part by the lymphatic vessels.

There is this similarity between the lymphatic and chyle vessels and the veins, that they convey liquid to the heart, and this from all parts of the body to which fluids have been conveyed by the arteries. Being provided with a capillary system of their own, both the lymphatic and the chyle vessels absorb through the walls of that system the surrounding liquid, in the same manner as is done by the veins, although the liquid is here probably of a different nature; and in the internal canal they absorb the chyle or the liquid extracted from the contents of the intestines. They do not, therefore, possess any apertures, but give passage to the fluids through the thin walls of the extreme capillary vessels, both of the lymphatic and chyle system, by endosmotic action. They form a net-work of little vessels, which are often placed very close together. Such a vascular net-work, fit for giving passage to fluids, covers the surface of the intestines and the skin, and exists in all parts of the body towards which arterial blood is conveyed. These vessels have been found, at least, in the muscles, in the shapeless ligamentary tissue, in the glands, and even in the vertebræ.

The common binding material of these vessels may best be observed in the intestinal flakes, which are small papillæ, hanging freely in the interior of the intestinal canal. On the surface of the walls of such a papilla we perceive cell-kernels, as on the capillary vessels of the blood vessels.

The tunics of these lymphatic and milk vessels consist of ligamentary tissue, interwoven with elastic fibres.

With regard to the liquid contained in them, we have to remark, that as they have no direct communication with the blood-vessels, they cannot contain the particles that are floating in the blood, and, therefore, not the blood-corpuscles either. The liquid that is present in them, and of which a quantity may be collected from those of a larger size, differs according to the organ from which the lymphatic vessel originates. This liquid may first be divided into two classes, viz., chyle and lymph. We shall treat of both when speaking of the fluids of the animal body.

QQ. Nervous Tissue.

This tissue is the noblest of all. In and through it matter performs the highest services that our mind can imagine to result from it. By means of a set of threads proceeding from the central organ, and diffused through the organism, the impressions made upon the senses are transferred to the brain, and through it affect the consciousness. On the other hand, the expression of the will is from that central organ transferred by means of these threads towards many parts of the body. Various actions are besides performed and maintained through their instrumentality, without the influence of the will.

The nerves are composed of fibres, originating from the brain in the form of roots, which are united together into a small stem. A number of these small stems again unite and form thicker stems, which take their way from the brain, and after having been divided into branches, enter into the organs of which they are to maintain the activity. By their endless ramifications in these organs they at last encircle even the microscopic particles, and return in most cases through the same bundle of nerves to the brain, where they are said to envelope certain cells in the grey matter. Having thus neither beginning nor end, they are actually closed threads, of which the extremities are bent round the cells of the brain and the elementary parts of the body. According to the investiga-

tions of Hannover and Kölliker, there are also nervous fibres connected with the nucleated globules, and Henle and Kölliker have observed a nervous fibre terminating in the bodies of Pacini.

In structure the nerves are of two kinds;—first, those which go to the muscles and the skin, called white nerves, and second, those which go to the intestines and blood-vessels, called grey nerves.

The *white nerves* are firm, shining, and surrounded by a solid tube, which consists partly of ligamentary tissue. This tube or cylinder serves to unite the nerves with the circumjacent parts. The section of a nerve presents internally a collection of small nerves (fig. 179, 1), each of which is enclosed in a little tube of solid ligamentary tissue (4), intermixed with thin elastic threads, these being united with one another by means of loose cellular tissue (2). The smaller nerves, enclosed within the larger ones, are again composed of collections of still smaller and thinner bundles of nerves, each of these being again surrounded by a minute tube. These thinner bundles are again composed in the same manner (fig 180), till we at last come to a minute bundle (2), which contains only fibres of nerves, united into one whole, but no more separable bundles. These last bundles are called primary, and the threads primary threads, primary fibres, or tubes (fig. 181 and 182).

The neurilema, or sheath of the stems, branches, and threads of the nerves, when boiled in water, produces gelatine, but only part of it is thus changed. Besides a capillary vascular net-work of extreme fineness, we find here and there threads of elastic tissue, which are insoluble in acetic acid. The neurilema, therefore, consists of gelatinous and elastic tissues, and capillary vessels.

In a stem of the nerves, therefore, we find the bundles of largest size down to the very smallest enclosed in such a case, until we have reached the primary threads of the nerves. Those threads are white, shining fibres (fig. 182, *a*), with dark, broad rims, possessed of a high refracting power. They are either placed parallel to the sheath, or are bent

into angles, or cross each other in vermicular directions. These fibres are exceedingly thin, but their diameter varies. In the nerves of sensation (the threads of Bidder and Volkmann) many of the thinner kinds are found; whilst in those connected with the muscles, the greater part are thicker (cerebro-spinal threads). There appears, however, to be no chemical difference between these two kinds. By pressure, the nervous fibres part with their contents entirely, and leave a little tube behind. The chemico-physiological nature of this tube is not known with certainty. It is not gelatinous tissue; neither is it probable that it consists of elastic tissue only, for potash dissolves it after a little while.

The contents of the nervous fibres, or the substance of the nerves proper, is during life-time perfectly homogeneous; but after death, a separation takes place between its two chief constituents,—the one, albuminous, diffused in water, —the other consisting of fats. This separation of its constituents is also effected by cooling, and rapidly by contact with cold water, so that the contents, from being homogeneous, are divided into a great number of globules, which float together, occupy the central part of the thread (fig. 182, *b*), and render it transparent, the albuminous matter being deposited in the form of a thick wall upon the internal part of the tube.

This separation is worthy of some attention. The chief constituents of the substance of the nerves are fat, albumen, and water. During life these are united into one whole, but they are separated after death. The protein substance is dissolved by acetic acid, but the fat is left; potash dissolves both; ether dissolves the fat, but leaves the protein substance behind. The latter is predominant in quantity, and hence acetic acid renders the contents of the nervous fibres liquid, leaving a bent, thick axis behind (fig. 184). By potash, the whole is converted into a thick, viscid fluid, and on the addition of water, globules of fat are left (fig. 185). Ether renders it thick and granular, and makes the axis disappear (fig. 186, *a*).

The change which the substance of the nerves undergoes

after death, is therefore not a coagulation, but a true separation of substances, which were united during life. This separation bears some resemblance to the rising of the cream from the cheesy matter of the milk, which two substances formed at first an emulsion-like fluid, and separate on being left to rest. The agglomeration of the particles of fat in the axis of the primary nervous thread, and the leaving behind of the albuminous matter mixed with water, upon the walls or tube of the primary fibre, is attended by a remarkable phenomenon, viz., the change of the nervous matter commences from the tube, and whilst towards the exterior there is a continual formation of granular matter, the axis of the cylinder becomes transparent. The protein substance, combined with fat and water into an emulsion-like body, constitutes the external granular parts, and the interior transparent axis consists of a large proportion of fat, with more or less protein substance, *without water*. The protein compound is present in both; by water the latter becomes as opaque as the former.

This cylinder-axis—a strange name certainly—is, however, often wanting, and is not entitled to so much attention as has been paid to it.*

* *The human ischiadic nerve, transverse section, dried.* It presents itself as roundish cut bundles (fig. 179, 1), having a very variable diameter, and interwoven for about the half of its extent with loose cellular tissue (2), in which fat tissue is occasionally found (3). When more magnified (fig. 180), the circular sections of the fibres of the nerve are seen to be in immediate mutual contact. On the addition of acetic acid, a secondary bundle parts with the loose cellular tissue, which becomes perfectly transparent, whilst the secondary bundle presents a transparent rim (fig. 179, 4, and 180, 1), by which it is entirely surrounded. By the continued action of the acid, the secondary bundle gradually presents a great number of subdivisions, being the primary bundles (fig. 180, 2), with transparent lines, which differ from the swelling cellular tissue (3). The primary bundles themselves are free from cellular tissue, and present a group of primary nervous threads, which retain their dark appearance, and lie in immediate proximity to one another. The primary bundles are of various thickness, and contain a number of primary fibres, from forty to one hundred and upwards. By the aid of a still higher magnifying power, the primary fibres are seen as of a somewhat circular appearance, and are found to consist of a thick rim, which contains concentric lines, and presents internally a more or less circular line, within which, exactly in the centre of the nervous fibre, there is a transparent point (fig. 181).

The *grey* nerves are different from the white, first, in respect of their fibres (fig. 189), which are surrounded by an integument that swells very much in acetic acid (2), being thinner, though in all other respects they are similar to the fibres of

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Around each kind of bundle, both secondary and primary, we find the neurilema rendered transparent by strong acetic acid, and consisting of swollen portions of ligamentary tissue, interwoven with threads of elastic tissue, which do not, however, proceed far. They are placed like a circle round the bundle.

When strong nitric acid is applied to the transverse section of the nerve, we see in the primary fibres a sharply defined rim, along with a transparent circular part, which is placed in the centre.

The last or tenth nerve of the spinal marrow of a frog.

It presents a great number of parallel nervous fibres (fig. 182, *b*) with double outlines, and irregular granular contents. A single one (1) has homogeneous contents, and is not at all granular. The stretching has caused the sheaths of some of the primary fibres to give way, and thus the axis of the cylinder,—which is much thinner than the entire nervous thread, very transparent, and not granular,—makes its appearance.

After having been kept for half an hour in a strong potash ley, the sheaths of the primary fibres appear to be dissolved, and the contents have become finely granular (fig. 183). By the action of the potash, the threads have been made on many places to break at right angles to the axis, and on other places they present alternate contractions and swellings.

By the action of strong acetic acid continued for an hour, the neurilema becomes more transparent, but in a less degree than the ligamentary tissue. The contents of the nervous threads becomes more transparent and swells; the whole is regularly inflated, and the double outlines have disappeared. Weak acetic acid, on the contrary, makes the nervous thread darker and granular. By strong acetic acid the albuminous parts of the contents become swollen and gelatinous, and thus the sheath is stretched out and becomes more transparent, whilst weak acetic acid cannot render the albuminous part gelatinous. In some of these, when placed in strong acetic acid, the contents has been bent in the shape of an S, sometimes even like a spiral, and then it does not occupy the centre (fig. 184, 1). This seems to be the axis of the cylinder, consisting of fats, forced in various directions through the particles of albumen, which are placed round the axis towards the sheath, and have become much swollen by the action of the acetic acid.

After a prolonged treatment with strong potash ley, the sheaths give way and part with their contents, which are left behind as a granular mass. The sheaths separate in the form of plates, and are subsequently dissolved by the potash. On the addition of water the contents are divided into a finely granular substance, which coheres a long time together, and presents itself in the form of little globules; the sheath, however, is completely dissolved. The albumen appears to be now entirely dissolved in the potash, whilst the fat is insoluble in the excess of alkali. The globules cohere together, become larger,

the white nerves; secondly, there exists a large quantity of cellular tissue (1) between the bundles of the grey nerves, and the threads of Remak are especially present in them, presenting themselves as pale, flat, transparent fibres, in which distinct kernels appear, especially after the action of acetic acid.*

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and remain behind in the form of large fat or soap globules, being frequently arranged in the direction of the former nervous thread (fig. 185).

The tenth nerve of the spinal marrow, not quite fresh when extracted with ether. The primary fibres are granular to the outermost circumference, and these granules are scattered through the centre and over the whole surface, but they are chiefly arranged into two rows, on the two external rims (fig. 186, *a*). Strong acetic acid makes the granules disappear, and the whole becomes homogeneous, transparent, pale and swollen (fig. 186, *b*). On the outermost rim, a sheath is very distinctly seen, consisting of a thin membrane, which is less transparent than the more interior parts.

The same, after digestion in a strong potash ley for an hour. By the addition of water, the primary fibre becomes very granular on the whole of its surface, which is to be ascribed to partial solution. Gradually the thread-like forms disappear, the granules decrease in size, and at last nothing visible remains. The absence of that part which we saw remaining after nervous threads, which had *not* been previously digested with ether, were treated with potash, confirms what we above suggested with regard to their constitution.

The sympathetic nerves of Bidder and Volkmann, from a frog (the connecting branch of the eighth nerve of the spinal marrow with the sympathetic nerve). They appear chiefly as thin threads (fig. 187, *a*), without double outlines. After having been kept for an hour in a strong solution of potash, they have become transparent and granular (*b*), and now they exhibit the most striking similarity with the cerebro-spinal nerves. (The threads of Remak are wanting. In warm blooded animals these are found in the sympathetic nerve.) After having been kept in strong acetic acid for an hour, their axis also has partly assumed a spiral or S-like appearance, and has become transparent (*c*). This arises from the swelling or extension of the albuminous matter against the fats in the axis, exactly in the same manner as in the cerebro-spinal nerves. These nervous threads, therefore, appear to have entirely the same character as the cerebro-spinal threads. (Donders and Mulder.)

* The human *nervus splanchnicus major*, a pure sympathetic branch (fig. 188). The section presents some secondary bundles (1), between which there is a large quantity of loose cellular tissue (2). By means of acetic acid, the whole becomes greatly enlarged, owing to the intermediate matter being swollen. The secondary bundles have a neurilema of their own (3), which differs from the intermediate matter, by the latter consisting of threads of ligamentary tissue, mixed with others from the elastic tissues, which have swellings here and there; in the neurilema, on the other hand, is a reticulated texture of elastic threads, mixed with threads of ligamentary tissue, and swelling but little in acetic acid.

When the fibres of the white nerves are predominant in them, they approach to the latter both in appearance and in function, and *vice versa*. In the branches of the sympathetic nerve (fig. 187 and 188), the second kind of fibres exists in greater number, and only a very few fibres of white nerves are found. If the threads, intermixed with these nerves, do really belong to the gelatinous and elastic tissues, then their nature can have no direct influence upon the function of these nerves.

The fibres of these grey nerves take their origin chiefly or exclusively from the ganglions, in which we find, besides the nervous fibres, a large number of either ovate or angular corpuscles (fig. 194 and 197), in the centre of which there is a clear, transparent, globular body (2) surrounded by a rim; whence these corpuscles have the appearance of two vesicles, the one enclosed in the other (nucleated globules). Of these little bodies a great number exist in the grey cerebral matter, and we shall treat of them presently. These irregular or ovate corpuscles are diffused between the fibres, and enclosed in cells of the neurilema, giving the ganglion a rough surface. The nervous threads that enter into such a ganglion, divide themselves into fibres, which are twisted round these bodies in every direction (fig. 194).

The manner in which the nerves communicate with the organs that are by them brought into action, is very variable. The muscles receive branches of nerves, which divide themselves in various ways, and form a kind of loops, which have

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The secondary bundles, after being treated with acetic acid, leave more spaces between them (fig. 189, 1) than the animal nerves. Between these, therefore, there must be threads of ligamentary tissue, which are made to swel by the acid. The primary bundles have, therefore, an integument, which becomes transparent and swollen after the application of acetic acid.

The primary fibres are very thin (threads of Bidder and Volkmann), and mixed with only a very few of a thicker kind. Their integument (2) swells and becomes broad after the action of acetic acid. The contents look dark (3).

The same splanchnic nerve, when fresh, and torn longitudinally, yields fine threads of the ligamentary and elastic tissues, the latter of which, on the addition of acetic acid, contract into spirals. The primary fibres are partly thick and partly thin, and further consist of Remak's threads, containing a great number of kernels. (Donders and Mulder.)

no end, but run across each bundle of muscles. Both the beginning and the end, therefore, of these nervous threads cohere with a nervous branch. In the skin the nerves of sensation divide themselves into very fine threads, which form a rhombic network, and these threads are again united into a new stem of nerves. Here again, therefore, we find the nervous fibres without termination. Even in the papillæ of the most sensitive parts of the skin, it is not the end of a nervous thread that enters, but only the bending of it; the same applies to the mucous membranes.

As regards the manner in which the nerves originate from the brain and spinal marrow, they commence, according to the observations we have made on them, in the form of simple fibres, which are from their commencement encased in a tube, in which the nervous matter is contained. The whole of the substance of the brain and spinal marrow is, as far as the white marrow is concerned, an accumulation of an innumerable quantity of such fibres (fig. 190), consisting of little tubes with medullary contents. These tubes vary in diameter, and the widest of them are placed at the interior part of the spinal marrow. These fibres unite into bundles, which pass visibly into the bounding nerves, but are at the same time laterally connected with each other and interwoven in manifold directions. The tubes of the nerves have a direct communication with those of the brain. Other fibres that exist in the nerves of the intestines and blood vessels, have not yet been found in the white matter of the brain, and we may, therefore, at present class the constituents of the white brain with those of which the finest nervous fibres,—that is, the tubes of the white nerves,—are composed.*

According to Valentin, the ends of the nervous fibres in

* *The white cerebral matter of a cow*, from the outermost layer of the cornu ammonis. It is a granular mass, mixed with some thin varicose nervous fibres (fig. 190, *a*). When taken from the hemispheres, we perceive a number of thin nervous fibres, interwoven in all directions (*b*), of which nearly the entire mass consists. All the fibres have wart-like swellings (the brain was three days old); some of them are much thicker than the rest, others much thinner than the general average. In the oblongated marrow we again find a few nervous fibres that are very thick (*c*), with thick coats and a distinct axis. Some of these are particularly thick. (Donders and Mulder.)

the brain are bent back and have no real termination, as in the organs towards which the nerves are directed. The white matter of the brain may be considered as an accumulation of the same tubes, of which, as we have seen, the ends of the nervous fibres consist.

A section of the grey substance of the brain, when observed from the exterior, appears under the microscope as a granular substance with little vesicles (fig. 191, *a*), in which we find globular and untransparent little bodies. When we examine it more towards the interior, we see a structure approaching gradually to that of the ganglia, as we come nearer to the medullary cerebral matter; that is to say, between the said vesicles we find nervous fibres, just as in the ganglia.

These vesicles are called nucleated globules (fig. 191, 192, *a*, and 193). They are large cells with a smaller one placed nearly in the centre, and in this internal cell there is a nucleolus. By acetic acid this nucleolus is rendered much more distinct, and the whole globule assumes a granular appearance. They resist the action of potash for a long time.

When highly magnified, the granular substance in the nucleated globules appears grouped into cells (fig. 191, *b*). In the centre we observe a distinct cell, with clear contents and a kernel, inclosed in a cellular membrane.* In this granular matter is contained a fatty substance.

Our knowledge both of the form of the elementary parts

* *The grey substance from the great brain of a cow.* It is a granular substance interwoven with a large number of blood vessels. After it has been moistened with water, there appear little globules (fig. 191, *a*), with both granular contents and a rim; within them we find a nucleus (cell), and within the latter a nucleolus (kernel). These nucleated globules, however, are but sparingly diffused through a mass of finely granular matter. Between them there is a large number of thin nervous threads. (We have not been able to observe these appearances without moistening, and the object has been examined uncovered.)

By the action of acetic acid the whole, including the globules, becomes more granular, and the latter acquire a clear broad rim. The kernel, nay the whole globule, becomes much more distinct. The remainder of the mass, not consisting of globules, is also rendered dark by dilute acetic acid; and, whilst in this liquid, the globules, which are now easily to be seen by means of their very distinct kernels, are plainly visible, we are at the same time enabled to see that the whole mass does not consist of such globules.

of the brain and nerves, and of their chemical composition, is equally insignificant in helping us to an acquaintance with the functions of these noblest of all organs.

The same form is peculiar to the nucleated globules, which we saw in the grey substance of the cornu ammonis of cow brain, after the granular matter, which is likewise found here in abundance, has been washed away with water. The whole is mixed with capillary vessels and with nervous fibres, having varicose swellings. Among the irregularly granular substances there exist, besides the nucleated globules, other globules of a granular appearance (fig. 192, *a*), which are a little larger than the kernels of the globules; and others still, of the size of these kernels, which are clear and transparent, like globules of fat.

By a very high magnifying power (fig. 191, *b*), we observe in the nucleated globules next the kernel a cell-like arrangement of the granular matter.

The grey substance of the small brain of a cow contains a large number of nucleated globules (fig. 193), interwoven with nervous fibres. The globules have cells with kernels, granular contents, and some of them on one side a pear-shaped prolongation (1). These globules are considerably larger in size than those of the grey matter of the great brain.

The grey cerebral matter. Part of the superior and exterior surface of the brain *of a living frog*, and a thin layer of the cervical substance below it, was cut away by means of a pair of scissors. Under the microscope, the nucleated globules are very faintly visible under the form of round and well-defined spheres, containing little granules. On the application of strong acetic acid both the defined edges and the granular contents become much more distinct. After a little time they disappear.

Another fragment put into water presents a very large number of the same nucleated globules; their outlines are in immediate contact, and appear to constitute the whole mass of the grey cerebral matter. Between them there is a large quantity of very small globules, which look like globules of fat, and do not form a part of the nucleated globules. On acetic acid being added, the nucleated globules distinctly appear, and on them we are able to distinguish a well-defined rim and granular contents. The globules are, however, in this case interwoven with transparent threads running in a determinate direction. By strong acetic acid the globules swell, become pale, and show very distinctly the presence of a kernel. After all else has been dissolved, or at least become invisible, the globules of fat remain.

The grey substance of the spinal marrow presents a large number of well-defined nucleated globules, interwoven with a great many nervous fibres. By acetic acid the whole is rendered transparent and dissolved, with the exception of a great quantity of minute globules of fat.

The grey substance of the brain in potash. The nucleated globules are left unchanged, aggregated into one group. After the addition of water they at first remain unchanged; gradually, however, they lose their form, and present the appearance of a homogeneous granular substance, in which a large number of minute globules of fat are floating, which, therefore, have not been saponified. These globules are exactly the same as those mentioned above.

The chemical nature of the brain varies with the part which is examined. The white matter of the brain appears to consist of the same substances as the primary threads of

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The ganglion gasseri of a cow. It contains large nucleated globules (fig. 194) surrounded by a great many nervous threads. One nucleated globule (1) contains a cell (2), of one-fourth of the diameter of the globule, and in this cell there appears a distinct kernel on the application of dilute acetic acid. After some time the wall of the cell has disappeared, the kernel has become very distinct, and the whole contents of the nucleated globule are granular. Without acetic acid, the kernel is still distinctly visible, but the outline of the cell is seen with difficulty. Strong acetic acid renders the outline (fig. 195, 1) of the nucleated globule broad, and it now appears to consist of threads (Remak's thread), in which we see a great many small elongated kernels. The granular contents of the globule (2) have plainly become cellular, consisting of a large quantity of little cells, with faint outlines and granular contents, pressed against one another, and filling the whole of the nucleated globule. After the inclosing fibres have been dissolved (the kernels remain undissolved and diffuse themselves), the whole globule is left without any distinct rim. After the more prolonged action of the acetic acid, the whole cellular contents become pale, and are gradually so completely dissolved, that nothing more can be distinguished, which is in consequence of the pressure and diffusion of the nucleated globules.

By a strong potash ley the globules undergo no change. Even after the addition of water they long resist its action; the contents of the globules being for a very long time still distinguishable as positive cells. Wherever the external covering is removed, the cellular contents are dissolved by the potash. This covering, however, resists the action of the alkali, and appears thereby to be insoluble in it.

While a large number of fatty or soapy spherules present themselves in the interwoven nerves, these are not to be seen in the globules themselves during the action of the potash.

There are a great many of the globules, upon the surface of which a nervous fibre lies coiled or bent in a vermicular direction (fig. 196). We saw in no place an undoubted connection between nucleated globules and nervous fibres.

Strong nitric acid, even after the action of an hour, has no effect upon them, further than that the whole has become less transparent and more granular. The walls of the nervous fibres have also been left unchanged. After an excess of ammonia has been added, the whole mass has become yellow, but the globules remain undissolved, and their contents are coarsely granular. These cells and kernels are invisible, the integument is swollen and fibrous. It is divided by pressure, and is not dissolved on the addition of water.

A thin section of a piece of the ganglion gasseri, when dried and put into water, affords a fine opportunity for seeing distinctly the fibres of Remak, or at least the thread-like outline (fig. 197, 1), and also a clear outline of the cell (2) which is found in every nucleated globule.

In a fresh piece, kept in potash for forty-eight hours, the contents of the

the nerves, viz., albuminous and fatty contents in thin tubes. The grey substance consists first, at least toward its exterior, of the same threads, and secondly of the nucleated globules, which seem to have fatty and albuminous contents, and further of the membranes of the larger and inclosed cells and their kernels. All the constituents of blood, without exception, are found in the soft and yielding mass both of the white and grey substance, as in every case these are mixed with blood vessels.

The following results have been obtained from analyses made by Lassaigne:—

	Grey substance.	White substance.
Albumen, ...	7·5	9·9
Colourless fat, ...	1·0	13·9
Red fat, ...	3·7	0·9
Meat extract, (osmazome), lactic acid, and salts, ...	1·4	1·0
Phosphates, ...	1·2	1·3
Water, ...	85·2	73·0

These results Lassaigne obtained from the brain of an insane person. Vauquelin obtained results from the white and grey substance, mixed together, which nearly agree with these. Denis found:—*

	From a person 20 years old.	From a person 78 years old.
Albumen, ...	7·3	7·8
Fat, containing phosphorus,	12·4	13·3
Meat extract (osmazome) and salts, ...	1·4	2·5
Water, ...	78·0	76·0
Loss, ...	0·9	0·4

Fremy states, that he has found in brain 7 per cent. of albu-

globules have become very dark and small, so that nothing more can be distinguished. On the addition of water they swell very much, but are but slowly dissolved; the wall does not even seem to dissolve at all. (Donders and Mulder.)

* Récherches sur le Sang, p. 30.

men, 5 per cent. of fats, and 80 per cent. of water (the remainder being osmazome and salts).

In these analyses, however, no attention has been given to the tubes of the primary fibres, nor of the cellular membranes of the nucleated globules.

The only peculiar constituents that are found in the results of these analyses, as differing from those found in any other part of the body, are the fats. We must acknowledge, nevertheless, that we are as yet but very imperfectly acquainted with the composition of the brain. The state in which the albumen exists in them, may be called coagulated; at least, it is insoluble in water, and so intimately combined with the fat, that the brain, when triturated with water, forms a liquid, resembling an emulsion of almonds. It is not dissolved in the water, for it is rendered liquid by acetic acid. Denis states, that the mass of the brain grows more solid in old age.

The fats may be extracted from the brain by ether and alcohol. The principal part of the fats of the brain consists of cholesterin, a fatty matter which exists in large quantity in the bile, and is also found in the blood (see p. 259).

Couerbe has obtained from the brain several kinds of fat which are peculiar to them. One of them, which he calls *cerebrot*, may be represented by the formula, $C^{180}\ H^{180}\ N^4\ O^{26}\ S^2\ Ph^{1\frac{1}{2}}$, which has been calculated by Berzelius. It is stated to be a pulverisable colourless fat, insoluble in ether, soluble in alcohol, from which it falls down by cooling, and incapable of being saponified.

A second fat from the brain is *cerebrol*, called by Couerbe elœncephol. It is said to have entirely the same composition as the following, and to be fluid, reddish coloured, soluble in ether, but with difficulty soluble in alcohol.

Cephalot, another fat, is of a dirty yellow colour, soft like caoutchouc, with difficulty soluble in alcohol, soluble in 25 parts of ether, and capable of being converted into a soap by alkalis. The composition approaches that of *cerebrot*. Its formula, as calculated by Berzelius, is $C^{180}\ H^{180}\ N^4\ O^{30}\ S^2\ Ph^{1\frac{1}{2}}$.

Stearoconot is yellowish brown, powdery, and when pure,

insoluble in ether. According to the analyses of Couerbe, its formula, calculated by Berzelius, is $C^{144} H^{144} N^{10} O^{11} S^2 Ph$.

These calculations have been given by Berzelius, merely as a possible expression of the results of the analyses made by Couerbe.*

It follows, from these analyses, that there is a variable proportion of phosphorus in these fats. The largest quantity is found in the brain of lunatics, and the smallest in those of imbecile persons.

Vauquelin also found free phosphorus in the brain, and not a trace of it in the albumen, after this had been extracted with alcohol. From this it appears, therefore, that the phosphorus is contained in the fats.

According to Fremy,† the fats indicated by Couerbe are not found as such in the brain, which, besides cholesterin, contains two soaps of soda, of which the one is solid, the other liquid. He asserts that the fatty acids of these soaps contain phosphorus, but no sulphur. Simon has confirmed the statement that they are soaps, for their alcoholic solutions produce precipitates with metallic salts.‡ These two fatty acids are called by Fremy cerebrinic and oleo-phosphoric acids. From the latter, olein may be separated by means of acids; the former contains 0·9 per cent. of phosphoric acid.

The component parts of the substance of the nerves are the same as those of the white brain. Vauquelin, who has examined them, states, that this substance contains more albumen, and less solid, but on the other hand, more fluid fatty matter than the latter.

The ganglia become very hard by boiling in water, and probably to a certain extent, correspond in chemical composition with the grey matter of the brain, as they both contain nucleated globules.

* Dierlyke Scheikunde. Nederl. Uitgave, Bl. 86.

† Comptes Rendus, Tom. 9, p. 703. Annalen der Pharmacie, 1841, Bd. 40, S. 69.

‡ Med. Anal. Chemie, S. 293.

CHAPTER VIII.

ABSORPTION OF FOOD BY PLANTS.

A. The Food of Plants.

We know, that besides water and air, animals take in, by peculiar organs, other extraneous substances, which serve to sustain their life ; and that for a great number of animals these substances are very variable and different, each of them being at the same time of a very complex nature. With plants, the case is quite different. Simplicity of food is a condition of their existence. This simplicity regards both the number and the composition of the substances which they absorb. These substances are water, atmospheric air, carbonic acid, ammonia ; those constituents of the soil which are soluble, such as ulmates, humates, geates, crenates, and apocrenates of lime, magnesia, potash, soda, ammonia, oxide of iron ;—and salts, formed by these bases with inorganic acids, of which the constituents are found in the ash of plants, silicates of potash and soda, sulphates, chlorides, phosphates, and other compounds.*

From this small number of materials, plants prepare that immense variety of substances which can be separated from them by artificial means.

In order to acquire some conception of this beautiful provision of nature, we must here distinguish two things, viz, that the substances mentioned must be taken up by plants, and

* In this enumeration no mention is made of the nitrates, or of organic substances containing nitrogen in other forms than that of ammonia—though such compounds are, I believe, extensively taken up by plants.—*J.*

that, being taken up, they must be partly elaborated within them.

The absorption of these extraneous matters might be performed in all plants through the same organs, provided they all had roots and leaves of exactly the same kind. This, however, not being the case, a considerable difference arises at once, as to the way in which this absorption of food takes place. In plants of different structure, we find organs, even very dissimilar, by which this absorption is effected.

As regards the second point, viz., the elaboration of the same nutritive substances, it is natural that the products should vary with the structure, and *vice versa*; and, therefore, that when there is a chemical difference in the substances that are obtained by the analysis of plants, there must actually exist a difference in their structure. A plant which contains vegetable alkalis (such as the various species of cinchona), must possess parts fitted to produce such a modification in the absorbed food, as will give cause to the formation of vegetable alkalis; another plant, abounding in acids (such as the species of Rumex), must possess peculiar parts for their production. The field which vegetable anatomy and chemistry have yet to investigate in this department, is too large for our present views. Almost nothing of this subject has yet been discovered.

The great variety of products which are found in the vegetable kingdom, cannot be derived from a difference in the substances that are taken up. We know, indeed, that many plants require a special soil to grow luxuriantly; but this peculiarity is more an effect of the difference in the inorganic, than in the organic constituents of the soil; and in cases where it is an effect of the latter, we cannot perceive any relation between the composition of the organic constituents of the soil, and of the substances produced by the plants. The lichens, for instance, which contain but little nitrogen, require sterile soils, some even live upon glass plates; whilst the saline plants require moist soils. In none of these kinds of plants, can we find any connection between their component parts and the organic substances that must be present in the soil in which they grow.

This manifests itself plainly on a mere glance at nature and her products. In a botanic garden, where the most dissimilar plants may exist near each other, the soil is not made up in a peculiar manner for each peculiar species or family; and in this artless nature we see the Antiaris toxicaria, one of the most poisonous of plants, from which the Upas poison of Java is obtained, surrounded by coffee-trees, which grow with the same luxuriance as the formidable Upas tree, which far overtops them (Blume in Rumphia). It is known to botanists, however, that there are some exceptions; for instance, the cicuta (water-hemlock), which is edible in Scotland, becomes poisonous in a moist soil.*

The chief cause of this difference of product, therefore, is to be found in a difference in the structure of the plants, by which the most different substances can be produced from the same or nearly the same organic and inorganic food.

It is of importance for us to consider how plants take up extraneous substances, what are the causes co-operating with this absorption, and by what organs these substances are taken up.

We have already stated that both gaseous and liquid substances are taken up by plants; but among the former all are not immediately connected with the nutrition of plants, properly so called. It is true, that the oxygen of the air oxidises a great number of substances; for instance, tannic

* This statement of Mulder refers, I believe, to the experiments of Dr. Christison, of Edinburgh, who has found that hemlock or dropwort (Oenanthe crocata), a deadly poison in many places, seems innocuous as it grows near Edinburgh; and that water-hemlock (Cicuta virosa), about Edinburgh, possesses the same harmless character. Still, even around Edinburgh, it is not known that the water-hemlock is edible in the ordinary sense of the term.

Nor is it the moisture of the soil that causes the difference in the poisonous qualities of these plants. The water-hemlock grows only in moist places, as on the edges of shallow lakes which are marshy in summer. The *Cicuta* must not be confounded with the *Conium*, which is a violent poison everywhere.

Upon this very interesting physiological question, the substance of Dr. Christison's results will be found in his *Treatise on Poisons*, 4th edition, under the heads of *Conium*, *Cicuta*, and *Oenanthe*.

An analysis of the ash of the poisonous and harmless varieties of these plants, and of the waters or soils in which they severally grow, might lead to interesting results.—*J.*

acid is often converted by it either into apotheme or into gallic acid, and many ethereal oils into acids or resins; but these remote actions have no share in the nutrition of plants, although they are among the chief active causes by which peculiar vegetable products are formed. But carbonic acid, which is absorbed by the leaves, deserves to be first treated of here. It enters into those organs either in the state of gas, or in the case of the aquatic plants dissolved in water, for the purpose of supplying to plants an important part of their food, after having been dissolved in the juices, and involved in the circle of chemical actions which take place there.

Every thing absorbed by the roots is offered to them in a fluid state, and this liquid may be either a solution of carbonic acid, or of organic or inorganic salts in water.

In order to give more method to our considerations, we must treat of the parts of plants that are concealed under the ground, and investigate in what manner they can draw their nourishment from the soil. The parts that have the next claim to our attention, are those exposed to the atmosphere, for there are two ways by which the food enters the plants, viz., through the roots as a liquid, and through the leaves as gas. We shall, therefore, consider the nutrition of plants from these two points of view.

B. The Root.

The root, or that part of the plant which is generally directed downwards into the soil (or into the water, and also into the air), is in many plants of a peculiar nature, by which the extraneous substances that are taken up must undergo a great variety of changes. Very frequently they appear as large masses, such as the bulbous or tuberous roots, in which the substances, collected from the soil, have to pass through a great number of cells, each filled with its peculiar matter, before they can reach the stem.

The great elaboration of the substances that are taken up from the soil, is, however, not dependent in all plants upon any positive difference in the structure, or any other peculiarity of the root. In the first place, a great many roots have

nothing peculiar in their structure, but are apparently mere prolongations of the stem of the plant. In the second place, there are some plants capable of being inverted, and whilst the roots, placed in the atmosphere, are converted into branches and produce leaves, the branches, on the contrary, become roots, and perform their functions.

A real difference, therefore, of the influence exercised either by the cell-walls or the contents of the cells, upon the substances absorbed from the soil, can only be assumed when the roots are of a peculiar structure. The difference between root and stem arises from the difference of the circumstances in which they are severally placed,—the one in a moist and dark place, in contact with organic substances, which are in a state of decomposition; the other elevated into the atmosphere, and its surface exposed to air, light, and heat.

Whatever may be the nature of the roots, they generally pass into fibres. In most cases, the roots divide themselves more and more, and at last separate into fibrils; but sometimes the thinner roots are covered with such fibrils, as with hairs. These fibrils are changed, fall off, and are renewed in the young roots, which are the seat of the most energetic vital action. The extremities of the roots have incorrectly been compared to spongioles. They consist only of the root bark, as the whole of the fibres do, covered with an epidermis, in which the stomata or apertures existing in the leaves are entirely wanting. There is one peculiarity, however, frequently to be found in the epidermis of the fibrils, viz., that the outermost cells are elongated beyond the surface, and thus produce a larger surface for the absorption of liquid.

It has been proved, by the experiments of Ohlert,* that not only the extremities, but likewise the side walls of the fibrils, absorb substances from the soil. He placed plants of Pisum sativum, Lupinus luteus, and Calendula officinalis in water, so that the extremities of their roots were three lines under the surface. Only the part of the roots which stood in the water retained its form, the remainder dried up completely. A number of plants was placed in water, in such

* Linnæa, 1837. S. 609.

a manner that the whole of the roots were immersed, while the extremities were above the surface. The roots continued to grow, even when their extremities were covered with varnish before they were placed in the water. It appears, therefore, from these experiments, that the side walls of the roots do actually absorb moisture, and that in this manner food is supplied to the plants.

As regards the other parts of the root, the cells and cell walls, vessels, &c., are in reality—with the exception of the pith, which is generally wanting—the same as in that part of the plant which is exposed to the air. In most cases they are even more simple in structure than in the stem. The vascular bundles are usually punctated spiral vessels and elongated thin-walled cells, placed in bundles together, and not divided. Further, all we know regarding the chemical composition of the stem, and what we consider as true with regard to the internal causes of the change of materials in the parts of a plant above the ground, is equally applicable to the component parts of the root. There is nothing peculiar to itself, by which the latter is characterised, and we may state in general, that the elementary parts of the plant that are above the ground, exert the same influence upon the substances to be extracted from the soil, as the elementary parts of the root itself.

Hence it is, that the general constituents of plants are found in large quantities in the root. In illustration of this we may point to the number of roots containing starch, dextrin, and sugar, and of those possessed of ethereal oils and other secondary products. Abounding, as they do, with nutritive liquid, they often reach a high degree of development, and at the same time a size proportioned to that excess of food.

In short, the aqueous solution of the substances that are present in the soil, which is absorbed by the roots, must penetrate through the cell-walls of the epidermis, and thence move on from cell to cell, and undergo in this manner a chemical change, which is—as regards the internal causes originating from the plant itself—analogous to that effected within the stem.

I must, however, draw attention to some differences between the root and the stem which are known, and may, possibly, although not probably, be connected with such functions of the elementary organs as terminate in a mere change of materials. These differences are the following:—first, that roots never grow in length in the same manner as the stem does,—so that two places, marked in adjoining roots, as being at certain distances from each other, have, after some time, retained the same relative position. Further, with the exception of the so-styled *adventitious* buds, they have never buds like the stems, and therefore they do not grow in length in the same way as the latter. Lastly, the difference existing between the roots and stems of some plants, for instance, those of the carrot, the turnip, &c., is no doubt an effect of the absence of atmospheric influences, and of the humidity and other properties of the soil on the root.

C. Conveyance of Food through the Root.

The substances existing in the soil in the state of liquids, are absorbed by the roots by endosmotic action; that is, the cells of the fibrils are filled with one liquid, and are surrounded by another, which is present in the soil. The latter fluid is less saturated than the former, and hence it penetrates through the cell walls of the epidermis of the fibrils, and thus the former is diluted. This takes place especially in the very young cells, which have either no epidermis at all, or only a very thin one, and are always found at the extremities of the roots, which grow by apposition. From these cells the liquid enters the others, and so throughout the whole of the plant,—all from the same cause.

Let us commence with the leaves. On their surface water evaporates; the liquid contained in the cells of the leaves becomes thereby more concentrated, and will now be diluted endosmotically by a thinner liquid, if this exists in the neighbourhood. This thinner liquid exists in the adjoining cells. On descending, the liquids in the various series of cells become gradually thinner, and thus the most dilute or

thinnest of all is present in the cells of the fibrils, whilst in the soil there must be a still more diluted liquid, in order that it may be possible for the liquid of the soil to enter into the roots, and for the liquid in the root to ascend into the plant.

Thus there is a close connection between the absorption of saps from the soil through the root, and their ascent into the plant. Both are to be ascribed to one common cause.

Hence it appears that the growth, the ascent, and the absorption of nutritive matter from the soil, depend on the evaporation from the leaves; and moreover, that only very dilute solutions can be taken up by plants. Finely divided substances, even those by which liquids are coloured, are generally not transmitted through the cell walls of the fibrils. No substance, therefore, can enter from the soil into the plant, unless in a state of perfect solution. But the solution being once perfect, the plant makes no selection, excludes nothing, but takes up everything according to the action of endosmose, provided only it has no destructive effect upon the cell walls of the fibrils. (See *Poisons of Plants.*)

It is known, however, that from mixed solutions of certain salts, plants take up some in larger proportions than others. This is a remarkable fact, and it has been represented in such a way, as if plants made a selection; as if they absorbed those constituents which are adapted to their nourishment, and excluded such as are noxious to their organism. This idea, by which plants are elevated to the rank of selecting beings, is not worthy of refutation. When, in the intestines of some animals, certain substances are taken up and others excluded, this is simply an effect of the same cause which operates in plants, viz., that some substances possess a higher capability of endosmotic absorption with reference to the membranes by which this selection seems to be made, than others. The same is the case with plants. The extremities of the roots of different plants have a different power of endosmose; and it is for this reason, that by all plants the same substances are neither taken up nor excluded. But, on the other hand, the same extremities of a root have a different endosmotic power

for different substances, as is the case with every membrane with which experiments on endosmose are made.

It is as true, therefore, that there is a molecular relation between the membranes that do or do not transmit, and the substances that are or are not transmitted,—as it is an incorrect idea, that either roots of plants or intestines of animals should have the *power of selection*.*

* The reader will observe that Mulder's reasoning in this and the preceding page, is directed in reality more against the term *selecting power*, than against the existence in the root of a power or property which has been so named in *popular* language. I have myself used that term in my published *Lectures on Agricultural Chemistry and Geology*, not as implying that anything like the power of animal volition existed in the root, but as most readily explaining, to the general reader, the actual result of the mutual actions of the root and the various substances it meets with in the soil. That the wheat stalk contains much silica, while that of the bean growing beside it contains almost none, implies that the one plant has taken up from the same soil much silica, while the bean has left it behind it—popularly, that the wheat has chosen or selected the silica, while the bean has rejected it. It seems hardly worth arguing against the use of such popular expressions in writings intended for general perusal, though it is very desirable that the true mode by which the result is brought about should be investigated by physiologists.

Mulder's ideas, based upon those of Dutrochet, are—

1° That the cell-walls through which liquids enter into the roots of plants act like membranes, and absorb or transmit in either direction any fluid with which they are brought in contact, provided it be not of such a nature as actually to injure or act chemically upon the cell-walls themselves.

2° That the liquid contained in the interior of a plant tends to an equilibrium or identity in every respect, chemical and physical, with the liquids in the soil and in immediate contact with the roots.

3° That the evaporation from the surface of the leaves and stems of a plant renders the fluid in the plant more dense, and thus causes a constant current of liquid inwards from the soil, and at the same time a tendency outwards of some of the excess of saline matter, which by this evaporation has been caused in the plant.

4° That the constant formation of new parts in the growing plants in which certain inorganic substances are contained and fixed, lessens the proportion of the inorganic substances thus taken up, as compared with that of the others which are present in the sap and in the watery solutions near the roots. To supply this failing proportion a larger comparative quantity of these special substances enters the roots, simply because the tendency is to an equality both in composition and in density on either side of the cell-walls which separate the interior of the plant from the external soil.

5° But though the cell-wall is thus said to have no special action of its own —it is admitted that, like all membranes, it transmits some substances, or that

In plants, however, the saps ascend in a peculiar manner, which appears to be different from the motion of the liquids in animals, and this peculiar kind of motion has induced some to form false conceptions. When poisonous substances are given to any animal, the intestines absorb but a small part of them, and in general, this part is smaller in proportion as the substance is more poisonous. But the case is different with plants. They may sometimes take up a large quantity of substances that are entirely unfit for, nay, poisonous to them. This could not be made to agree with the above power of selection, and it was thought, therefore, that the absorbing organs of the roots were destroyed by the poison, and then by capillary action the liquids were taken up through open tubes, and conveyed through the plant.

Vogel* has endeavoured to refute this assumption, by showing that plants in their natural state do actually take up poisons, without their roots having received any injury. He saw them absorb salts of peroxide of copper, which were, at the same time, converted into salts of the protoxide. They further absorbed chloride of magnesium, sulphate of magnesia, nitrate of potash, iodide of potassium, sulphate of zinc, nitrate of nickel, nitrate of cobalt, acetate of lead, sulphate of protoxide of manganese, and bichromate of potash. Salts of mercury and silver were also absorbed, and the oxides

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some substances pass through it more easily and in greater abundance than others, so that potash or silica may enter more easily and abundantly than soda, lime, or alumina; that is to say, that the membranes have the property of excluding, to a greater or less extent, certain substances which are presented to them, and of admitting others. Put a sea weed in salt water, and in virtue of this property it takes up potash and phosphoric acid in far greater proportions, compared with the common salt, than they exist in the sea water.

This supposed property of the cell-walls is in effect that which has been distinguished as the selecting power of the roots. Those who assent entirely to this doctrine of endosmose may think it more correct to speak of the special endosmotic power of this and that root, as being the cause of the special nature and proportion of the inorganic compounds which are found in the plant to which it belongs; but I doubt if the general reader will so clearly understand the mode of action when clothed in this phraseology, as when it is simply described as a *quasi* power of selection.—*J.*

* Erdmann und Marchand's Journ. Bd. 25, S. 209.

reduced to the metallic state. Corrosive sublimate was taken up either unchanged or reduced to calomel. All these salts had the effect of killing the plants. In connection with these experiments, a great many others might be quoted which have all given similar results.

The only conclusion that can be drawn from all this is, that under certain circumstances, both poisonous and harmless substances are taken up by plants; but this conclusion might have been long ago arrived at from known facts.*

The injurious action of a variety of substances upon plants has been proved by experiments of Goeppert.† This action is such that it must be called poisonous, like the correspond-

* Trinchinetti has published a number of experiments (Bibl. Univ. Nov. 1843, p. 346) regarding the power of uninjured fibrils to absorb solutions of salts. He saw plants take up dilute solutions of the following salts, viz.:—prussiate of potash, nitre, chloride of sodium, sulphate of copper, acetate of lead, chloride of barium, iodide of potassium, sulphate of potash, sulphate of zinc, sulphate of magnesia, alum, nitrate of lime, chloride of ammonium, traces of limewater and arsenious acid; but little iodide of potassium; and of corrosive sublimate and nitrate of silver, nothing at all. From a mixture of two salts,—common salt and nitre, for instance,—different proportions are taken up. Neither starch, sugar, infusion of quassia amara, nor colouring matters were taken up. Humate of potash was absorbed, but decomposed in the root. He could not find it in the plant.

With regard to Trinchinetti's remarks, as to the different proportions of two very soluble salts which a plant takes up from a mixture of the two,—a fact that has been frequently observed before,—we must remark in our turn, that the remote constituents of the plant can only have an indirect part in this action, and that, therefore, no power of selection can be ascribed to the plant as an individual. This difference depends, first, on the structure of the cell wall of the fibrils which transmit the one or the other solution with more or less difficulty; secondly, it depends on the formation of certain constituents within the plant, for instance, in the fruit of cerealia much phosphate of lime is deposited; this salt, conveyed with the juices of the plant, is secreted from it along with the albumen, consequently the juices being deprived of part of this salt, have it again supplied from the soil, according to the laws of endosmose. In so far the production of new substances is connected with this so-called selective power of plants. If it were possible, that after a mixed solution of sulphate of soda and nitre had partly been transmitted endosmotically through a membrane, the one were immediately removed from the solution, it would be transmitted in larger proportion than before.

† Vers. zur Beförderung des Gartenbaues in Preussen, Bd. 6. The experiments of Bouchardat (Comptes Rendus, 1843, p. 112,) may also be consulted.

ing one in animals. This shows that the action of poisons upon plants and animals is to be regarded as an ordinary action of matter upon matter; of which, however, the influences upon the organism differ with its structure, and with the substances of which it is composed. It is therefore entirely different in different organic bodies. Those differences appear even in different individuals of the same species, inasmuch as they experience different effects from the same poison. They become gradually greater between different species, genera, or tribes, and are greatest in the different kingdoms of Nature.

The fact, that plants may be poisoned by the same substances which have an injurious effect upon animals, does not by any means indicate that a certain principle—the so-called vital principle—is attacked, but merely that the poisonous substance produces a change in the condition of the substance of which the plant consists. Let us assume, for instance, that a salt of lead is absorbed by a plant. This salt cannot enter any cell without rendering the albumen solid, thus making a connexion with its constituents impossible, and wherever this takes place, every action within the cells must cease. The transmission of the liquids from the root upwards becomes obstructed; and, in consequence of this, the change of materials in most parts of the plant is in danger of being arrested. In other words, the plant is affected with disease and dies, unless this cause can be removed.

Other substances, again, may produce disturbances in the constituents of plants of a different kind from that of the lead salt. It will always be a modification of the change of materials, and not an attack upon the so-called vital principle, which has in this case again been assumed for the sake of explanation. Even when the sensitiveness of the Mimosa pudica is destroyed by narcotic substances, the same view of the matter holds good.

We further learn, from what we observe in the poisoning of plants, that in animals the nerves have no other part in the action of the poison upon the organism, than that of transmitting its influence. To assume that an action is

exercised upon the nerves themselves, is wrong; and we ought, therefore, not to proceed from this point in considering the influence of poisonous substances upon animals. Plants have no nerves, and yet they are also capable of being poisoned.

The effects of poisons on plants are more difficult to be observed and determined than on animals. Plants do not die suddenly, but gradually. It is difficult to say with certainty when their death commences, and when it is completed. When, therefore, they die by means of poison, we find many difficulties in attempting to make a comparison between the poisonous action of different substances upon plants of the same species or genus.

Miguel* submerged cut plants in pure water, and at the same time other specimens of the same in solutions of ammonia, acetate of lead, prussiate of potash, camphor, laurel water, watery extract of opium, and extract of hyoscyamus, and found these different substances poisonous to a great number of plants. Opium, hyoscyamus, laurel water, and other poisons, which are said to act upon the nervous system in animals, kill the plants as well as sugar of lead, which is said to act chemically upon the animal organism; that is, to form insoluble compounds with constituents of the body. A species of hyoscyamus died sooner in extract of opium than in extract of hyoscyamus. Schübler and Zeller even found that narcotic extracts introduced into the plants by means of incisions had the effect of killing them.

The first appearances presented by a poisoned plant are the following. Its power of absorbing liquids diminishes, the petals and branches become pale, the grey and other coloured parts are decolorised, and after this there appear positive signs of approaching death, that is, of a disturbance of the harmony of the several organs, terminating in an entire destruction of that harmony, or the discontinuance of every normal function.†

* Bulletin, 1838, pp. 137 and 160.

† On the subject of the absorption of mineral poisons by plants placed in an ordinary soil, may be read,—Verver, in dissertatione, qua inquiritur num pub-

That the roots of plants excrete salts which the plants do not require, has not been proved by one single experiment; the result of that made by Princep with acetate of lead was owing merely to exosmotic action.* I would pass it over in silence, if it did not appear to me to result from the known phenomena of endosmose, that no entrance of solid substances *into* the roots can take place, unless these are exchanged for outgoing substances. Not one phenomenon of endosmose can be quoted, of which an equal density of the exchanging liquids is not the final result, and where there is not invariably an *exchange* in two opposite directions. It appears to me, that the fibrils, when absorbing the liquid from the soil by endosmose, must at the same time *exchange* their constituents with those of the soil. In this manner, therefore, but not in the sense of excretion, the roots may actually impart substances to the soil.† The descent of substances from the leaves to the stem, and from thence to the root, which can now no longer be denied, has strengthened the probability of this supposition, viz., the endosmotic exchange of the constituents of plants both mutually and with those of the soil. If, however, such an exchange does take place, this must be in a very slight degree, because the liquid of the extremities of the fibrils contains but a very small proportion of solid substances.‡

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licæ sanitati nocere possint venena metallica, quibus conserantur agri, ad occidenda animalia nociva, Groningæ, 1841. It appears from experiments made by Verver, that small quantities of metallic poisons are retained in the soil, and do not enter into the plants, with the exception, however, of salts of copper and iron.

* The opinion, first put forward by Brugmans, and afterwards by De Candolle, which had been verified by Macaire Princep, viz., that plants excrete through their roots certain substances which can be injurious to some plants, has been negatived by experiments of Braconnot (Annales de Chemie et de Physique, tome 62, p. 83.) According to the latter, these noxious excretions of plants have no existence, and Princep appears to have been in error.

† See note, p. 623.

‡ Rayney has observed (L'Institut. 1844, N. 551), that a great number of plants absorb much more water when placed in pure water, than when in weak solutions of different substances. In the latter case, the portion which has not been absorbed has the same specific gravity as the whole quantity had before the experiment.

D. The Inorganic Food of Plants.

Among the nutritious substances that are indispensable to plants, the inorganic constituents of the soil have an equal right to be reckoned as the organic constituents, including carbonic acid, water, and ammonia.

These inorganic substances are derived not from the rain-water, which contains so little solid matter, and which is especially deficient in that which exists in plants, but from the decayed rocks, from which the powdery soil has been formed, and from which they are dissolved out by the rain-water. Some of these are found in ordinary river-water; more, however, in water which has passed through strata of the earth, and which is known by the name of spring-water. Pliny of old has justly remarked, "tales sunt aquae, qualis terra per quam fluunt."

This water, which penetrates all decayed rocks, and therefore all soils, in manifold directions, is supplied to plants through their roots.

The depth, however, at which this water is in a state of equilibrium, is generally too great to admit of being reached in mass by the roots of herbaceous plants. The level of the water in the earth is in many places situated very deep, most frequently at least some feet below the surface. These plants, therefore, would at first view seem to live chiefly by means of the rain-water, with which the upper layers of the earth are moistened.

If this were the case, the vegetable kingdom would be in an unhappy condition indeed, for the rain-water, falling upon the surface of the earth, enters there, washes out the upper layers, and sinking deeper, carries along with it a large portion of the soluble salts. If, therefore, no other cause were in operation to counteract this one, short-rooted plants could not obtain the inorganic constituents which are necessary to their existence.

Nature has provided for this in the following manner. Soils always contain at a certain depth collections of spring

water. This water holds in solution a variety of salts which are necessary to plants, and among them are also those salts which have been washed out by the rain-water from the upper layers.

In dry weather the surface of the soil gives off by evaporation nearly pure water. By capillary action the dried upper layers are again supplied by those below with water containing various salts. From this weak solution pure water is again separated by evaporation, and is again replaced by water containing salts. By this repeated process the salts of the water that was raised by capillary attraction, remain behind in the upper layers of the soil, and are abundantly supplied to the roots, even though the water under ground may hold only few salts in solution.

It is in this manner,—by capillary attraction and evaporation,—that the salts which had been washed out by the rain from the upper layers of the soil, are again restored.

Plants obtain in this way chlorides, sulphates, and carbonates of lime, magnesia, potash and soda, and also silicate of potash, but these are not the whole of the salts that are found in plants. In rye and a great many other plants there is a large quantity of phosphates. These are not found in the water, and rye cannot, therefore, grow luxuriantly, unless it finds these indispensable constituents in the soil. Phosphate of lime is actually present in many fertile clay soils, and if it be wanting, it is effectually added to the soil as a true manure. It needs no argument to prove that the fertility of soils, in which plants are cultivated that contain much phosphates, without which they cannot live, depends on the proportion of phosphates contained in the soil.*

The salts which must be supplied to the roots, are not merely those which constitute the inorganic constituents of plants. Almost all plants contain bases combined with neutral organic substances, for gum and mucilage always occur in combination with lime. Besides, there are a great many plants

* Fownes (Ann. de Chem. et de Phys. Mars 1845, p. 377) found that volcanic rocks, such as trachyte, basalt, lava, always contain phosphoric acid. This is of importance, and ought to be more carefully investigated.

with organic acids, which require bases to exist in those plants. Acids are seldom found in a free state there, unless we count as such the half of the oxalic or tartaric acid, which are only combined with water, and are found as such in the salt of sorrel (oxalate of potash with oxalate of water), and in cream of tartar (tartrate of potash with tartrate of water). Tannic acid, however, and a few others, are present in a free state, probably because they could find no bases to combine with, having been formed in places where none existed.

The potash of these two salts—salt of sorrel and cream of tartar—has plainly been extracted from the soil, and the same remark applies to all the organic salts of plants containing inorganic bases.

These bases,—potash, soda, lime, and magnesia—are very differently distributed among the different parts of the same plant, and their presence is evidently connected with the functions of the parts in which they are found in greater or less proportion.

We may ask, in what state are these bases conveyed into plants,—as organic salts,—ulmates, humates, geates, apocrenates, and crenates—(see p. 165), or as sulphates, carbonates, and chlorides?

This question may be answered as follows. In the first place, nearly all plants contain organic substances in which sulphur is present, viz., albumen and gluten. This sulphur can only have been derived from the decomposition of sulphuric acid, and the latter again from sulphates. Sulphates, therefore, can be decomposed and yield sulphur, and the base of the sulphate being set at liberty, may enter into combination with some organic acid within the plant, for instance, aconitic or quinic acid, &c. Now, as these substances containing sulphur—albumen and gluten,—are universally present in plants, the decomposition of the sulphates and liberation of their bases is universal also.

But there is still another source of free bases. Some of the protein compounds in plants contain free phosphorus. This indicates the decomposition of phosphoric acid supplied from phosphates, and, consequently, the liberation of their bases,

which are thus left to enter into combination with organic bases.

There is no reason for assuming a decomposition of chlorides in plants.* It is, however, worthy of remark, that in sea and coast plants, and some animal productions in seas and on shores, iodine does occasionally exist in the state of an organic elementary substance. In spunge, for instance, iodine is found combined with carbon, hydrogen, nitrogen, and oxygen, in the same way as sulphur is in albumen.

But we may assume as certain, that carbonates are decomposed in plants. When, for instance, oxalic acid exists ready formed, it will decompose any carbonate that is present, expelling the carbonic acid, and combining with its base. But it appears also, from the experiments of Draper, that carbonates are directly decomposed by plants. Whenever, therefore, a free acid is produced, the carbonates that are present must lose their acid; and on the other hand, whenever a carbonate is decomposed by the plant through the action of light, an alkali is set free, and there is an opportunity for the production of an alkaline salt containing an organic acid.

If we, moreover, consider that the roots of plants absorb silicate of potash or soda, and that the acid of these plants is in several places separated, and potash or soda set free;—further, that humates, ulmates, geates, apocrenates, and crenates of potash, soda, magnesia, lime, and iron, enter into plants, and that immediately after they have done so the organic acids of these salts are decomposed;—we perceive that there are abundant sources for the liberation of inorganic bases, which may combine within the plants with vegetable acids as they are formed, and also with neutral vegetable substances, such as gum, mucilage, dextrin, pectose, cellulose, incrusting matters, cuticular matter, &c.

As a result, therefore, of the well-known decomposition of sulphates, phosphates, carbonates, silicates, ulmates, hu-

* Chlorine has been observed to be given off by the leaves of plants. I differ from Mulder also, in thinking that there is much reason to believe that common salt (chloride of sodium) is decomposed by plants. See my *Lectures on Agricultural Chemistry and Geology*, 2d edition, p. 157.—*J.*

mates, geates, apocrenates, and crenates, in plants, inorganic bases are liberated, which may combine with organic acids that may be formed, and produce salts of potash, soda, lime, magnesia, oxide of iron and oxide of manganese. Some of these bases may occasionally replace each other in whole or in part. Thus soda may be replaced by potash, ammonia by soda, or *vice versa*, and magnesia by lime. The chemical properties of these bases are very analogous, and, therefore, when they exist in a soil, there are plants—not all plants, however—which take the one instead of the other.

It is well known that there are limits to this exchange of bases. Plants on the coast which require soda, do not grow in soils containing potash but no soda. And although we may be able by cultivation to accustom plants to a certain difference in this respect, it is, nevertheless, most improbable that a plant, after having taken up bases that are quite different from those which are originally peculiar to it, should preserve its original chemical character. The seed of the tobacco plant from *Havannah*, when transplanted to *Java*, produces tobacco approaching to that from the Havannah; but even the first seed sown in Java yields a produce which differs to some extent from the Havannah variety, and after the seed has been collected and again sown several times, the Havannah tobacco degenerates at last into Java tobacco. The only reason of this must be the difference of the bases existing in the several soils of *Havannah* and *Java*.

It has always been thought that the difference between cultivated and wild plants was to be ascribed to an excess of food, which is supplied to the former. There is no doubt that this is the cause to a certain extent; but we ought to regard as an additional cause the difference in the inorganic constituents of the soil.

Although it may be true, therefore, that some bases replace each other in plants, this does not at all imply as a certainty that the plants thereafter retain their character unchanged, and exhibit the same properties and the same organic constituents. Experience shows that the reverse is the case, for there is a considerable difference between the bases

of plants of different qualities, both in regard to their use as food and in pharmacy.*

No sufficient distinction has yet been drawn as to which bases exist in the solid, and which in the liquid parts of the plant. And yet such a distinction would be of great importance. The expression *in the plant* is crude and vague. The solid parts of a plant are very different in nature and properties; and hence again the expression, *in the solid parts of the plant*, is un-scientific. In this respect science has hitherto done almost nothing.

It would indeed be a marvellous coincidence of innumerable different circumstances, if there were really such a relation between the bases which are found in the same species of plant, cultivated on different soils, that the quantity of oxygen in the bases was always constant. Liebig thinks that this is actually the case, but it requires no proof that this can only happen by accident. We might suppose from general principles, that the quantities of oxygen are about the same in the same plants; but it follows from the analyses that have been made in investigation of this point, that this relation can only be held as approximately true; and I do not consider it as a rule worthy to be received in science, "that the proportion of oxygen in all the alkaline bases taken together is unchangeable in all circumstances—upon whatever soil they may grow." Neither has this rule been confirmed by experience. (See hereafter.)

In the analyses that have hitherto been made, the salts of *all* the organs of the plants, that is, of the contents of the cells, &c., have been analysed together, and therefore no greater accuracy has been arrived at than can be attained by experiments *in mass*, which must necessarily always give but a certain approximation. But besides, the ammonia is not to be overlooked, for this is an important base, which may undoubtedly replace the potash and soda of the food and *vice versa*; it must, therefore, have the greatest possible influence.

* Unger has classified plants according to the inorganic constituents which they take up from the soil.

both on the quantity of the solid bases that have entered into the plant, and upon their products within the plant.

The analyses of Berthier* and De Saussure have shown a great difference between the *proportions* of the bases that are found in the same kinds of plants, grown on different soils. It appears to me that this difference is at least partly to be ascribed to a difference in the proportions of ammonia; this being a base, through which *all* the acids the plants require can be supplied to it from the soil, forming salts with them that are very readily soluble.

In short, if it is really a law, that the quantity of oxygen contained in the bases of the plants is constant in the same species wherever it has grown, then it is equally true that this relation cannot be found by burning the plant and analysing the ash, because one of the bases, viz., the ammonia, is volatilised by the combustion, and is not determined along with the others.

It cannot be objected to this, that nearly the whole of this ammonia, as a base, disappears in the plant and is used as organised food in the same manner as carbon and oxygen. For we must consider on the other hand, that the cellulose, in whatever form it may appear—that all the protein compounds—in a word, that all the solid parts of a plant, also remove a quantity of the potash, soda, lime, and magnesia, as so many bases with which they combine, and thus render them inaccessible to the action of the vegetable acids. Whilst, therefore, the ammonia passes into organic substances, the acids which were combined with it are set free; and again, whilst bases are combined with neutral substances, the acids that were united to these bases are also liberated.

Although I conceive that there are a great many causes which may operate to produce a certain approximation, yet I consider the existence of the rule, as a rule unproved; neither can it, in my opinion, be proved in the present time. If limited to the acids that are found in the contents of the

* Annales de Chim. et de Physique, tome 32, p. 248.

cells, such as tartaric acid, &c., then no rule at all can be established, for there exist some acids in plants in a free state, such as the tannic acid, the citric acid, &c., and to these, therefore, the rule could not be applied.

When the carbonic acid of the carbonates is replaced by some organic acid, under the co-operation of an additional quantity of carbonic acid, then there must necessarily be found a salt of an organic acid with an inorganic base, in proper chemical proportion. But in this case the law asserted by Liebig, would imply that cream of tartar, for example, is represented by the formula

$$C^4 H^2 O^5, HO + C^4 H^2 O^5, KaO,$$

a truth which certainly nobody will call in question.

What proportion the inorganic bases may bear to the neutral parts of the plant that have a definite form, is at present still unknown, and as these parts contain no vegetable acids, but the bases are combined either with the cellulose or the incrusting matter and mixed with other inorganic salts; and as, further, these parts with a definite form constitute the chief mass of a great number of plants, this still remains a point for investigation in vegetable chemistry, to be pursued in the same way as it has been carried on in animal chemistry with regard to the bones.

Finally, the idea once current that plants can seek for bases in the soil according to their wants may be safely considered as erroneous. We do not know the existence of such a power in plants. But it has been found to be true, that plants of different species placed close to each other in the same soil and under the same circumstances, after being burnt, leave different proportions of ash. This shows that, by a different degree of evaporation and other causes, mentioned at page 621, plants absorb from the soil a different portion of water, and consequently, also, of the salts contained in it. This is the reason that some plants require for their existence a much moister soil, and water containing a greater proportion of salts than others. According to Berthier, 1000 parts of oak wood left 25 parts of ash, whilst the same quantity of linden wood yielded 50 parts.

It appears to me, therefore, that it is impossible to indicate any general law with regard to the presence of inorganic bases in plants. With the single exception of Mycoderma vini, all plants that have hitherto been analysed contain inorganic constituents. It is known that part of them is combined with acids in such plants as contain acids; for instance, in the Peruvian bark, quinic acid is combined with lime; in the various kinds of sorrel, oxalic acid is combined with potash; and in the grasses, tartaric acid with potash and lime. But although they serve in the plants just mentioned, and in others containing acids, to neutralise these acids, and their quantity is necessarily proportionate to that of the latter; yet in a great number of plants those acids are wanting, although these very plants contain a considerable quantity of bases—and *vice versa*, in some plants which are characterised by the presence of free acids, bases are not present. In every cell-wall, however young, in the spiral threads, in the incrusted ligneous cells, in short, everywhere, these bases are found. They are therefore indispensable to the life of plants; when they are wanting, the plant is languid, and does not produce that substance which it otherwise would, because it grows in a sickly manner. But this does not yet entitle us to conclude, that the substance which is not produced in consequence of that sickly condition itself directly requires these bases for its production. Starch, for instance, contains almost no inorganic matter at all. Its production is possible without the direct influence of that inorganic matter. But the contents of the cells, through which the dextrin of the saps must be converted into starch, is disabled from performing this function, if they do not contain the requisite bases. *It is from this cause* that no starch is produced, although the latter does not itself require any bases. The same remark applies to the vegetable acids. If we should conclude that a plant which is deprived of the necessary quantity of potash, does not produce any oxalate or tartrate of potash, because the acid that is to be formed finds no base to neutralise it, then in my opinion, we should err. The want of potash makes the plant sickly: the substances that are present in it

undergo a change, different from that which would have taken place had alkaline bases been present: and it is this general diseased state, which is an indirect effect of the absence of potash, that causes the non-production of oxalic or tartaric acid. A plant to which no inorganic substances at all are supplied, produces *nothing:* we should, therefore, be equally justified in asserting that everything—for instance, the production of vegetable alkalies, ethereal oils, colouring matters, &c.—is effected by the inorganic bases, as we are in assuming that the production of acids is effected by them.

This is the only connection that I can perceive between the proportions of acid which may be obtained by the analysis of a plant, and that of base which has been supplied to the latter as food. The larger the quantity of base—up to a certain limit—which can enter into a plant, the more luxuriantly the plant will grow and produce its peculiar substances; the larger, for instance, will be the quantity of acid which is formed and at the same time fixed; that is, which will be removed beyond the change of materials in which every part of the plant is involved. It is, in my opinion, in this manner, and in this manner alone, that we can explain the otherwise mysterious phenomenon, that there is a regular proportion between the quantity of acid and base; for, whilst the acid is produced in the fruit, for instance, we cannot imagine that the roots possess the power of securing that a sufficient quantity of potash is supplied to the acid in the fruit. For this reason fruits remain sour in wet seasons; because from them that evaporation of water cannot take place, which promotes the entrance of vegetable sap into them, carrying with it a sufficient quantity of base to neutralise the acid. Hence ripe fruits ought to leave more ash than unripe ones, and we cannot, therefore, place implicit reliance on the analyses of Berard.*

* Johnston (Elem. of Agric. Chem.) obtained from 1000 parts of straw of unripe wheat, burned five weeks before its ripening, 40 parts of ash, whilst straw taken from the same clay soil after having come to maturity, yielded 50 parts out of 1000.

The results of Berard are mentioned in the section entitled the "Ripening of Fruits," which follows hereafter.

Finally, there is a greater or less quantity of free acid contained in sour and unripe fruits, which is a proof that the acid has been formed before a sufficient quantity of inorganic bases has been taken up; and which shows, therefore, that the quantity of acid prepared is not in proportion to that of the base which has been supplied.

It follows from what has here been said, that I cannot subscribe to Liebig's opinion (Journ. de Pharm. et de Chem. 1843, tome iv. p. 87), concerning the function of the bases in plants, which he supposes to be the production of acids, and that I feel bound to view this important subject in the growth of plants in a different light.

I shall now mention a few analyses of ashes of plants, which have recently been made under the direction of Fresenius and Will (Annalen der Chemie und Pharmacie, June, 1844).

They divide the ashes of plants into three principal groups, viz.:—

1. Ashes of which the chief constituents are earthy and alkaline carbonates. These are obtained from the different kinds of wood, herbaceous plants and mosses, containing much organic acid.

2. Ashes having earthy and alkaline phosphates for main constituents, to which belong the ash from seeds.

3. Ashes with silicic acid as a chief constituent, such as those of the stems of grasses and equisetaceæ.

It is plain that this division does not embrace every case, yet it affords certain distinct points of classification.

In tobacco from Hungary they found 18.9 to 27.36 per cent. of ash; in the leaves of Fiscum album, 10.93 per cent., and in the stem of the same plant, 3.67 per cent.; in Pyrus malus (the apple), 1.29 per cent.; in mosses from an apple tree, 3.62 per cent.

This mode of accounting for the sourness of fruits will not bear criticism, nor the conclusion drawn from it, that ripe fruits ought to contain more inorganic matter than unripe. If the organic acid which causes the sourness be transformed into sugar, the fruit becomes ripe without any necessary change in the proportion of inorganic matter. But I have elsewhere treated this subject at length.—*J.*

Out of ten different ashes of tobacco, we shall quote the analyses of three from different places:—

	I.	IV.	X.
Potash, ...	29.08	18.20	11.21
Soda, ...	2.26	...	...
Lime, ...	27.67	27.86	47.03
Magnesia, ...	7.22	15.73	12.77
Chloride of sodium, ...	0.91	11.41	2.58
Chloride of potassium, ...	...	3.92	2.97
Phosphate of iron, ...	8.78	6.80	6.30
Phosphate of lime, ...	...	...	...
Sulphate of lime, ...	6.43	10.11	5.11
Silica, ...	17.65	5.97	12.03
	100.	100.	100.
Oxygen contained in the bases, ...	16.06	16.99	20.05

These analyses show most distinctly an exchange of bases. The difference, however, between the quantity of oxygen contained in the bases of Nos. 1, 4, and 10 is so great, that any stability of the proportion of bases in the same kind of plants is entirely out of the question. The cause of these differences may be, first, the proportion of saltpetre, which is not mentioned here, and in general a difference in the respective quantities of juices.

	Red wheat.	White wheat.	Rye seed.	Rye straw.	Peas.	Apple tree.
Potash, ...	21.87	33.84	32.76	17.19	39.51	19.24
Soda, ...	15.75	...	4.45	...	3.98	0.45
Lime, ...	1.93	3.09	2.92	9.06	5.91	63.60
Magnesia, ...	9.60	13.54	10.13	2.41	3.43	7.46
Oxide of iron, ...	1.36	0.34	0.82	1.36	1.05	...
Phosphate of iron, ...	...	...	...	...	...	...
Phosphoric acid, ...	49.32	49.21	47.29	3.82	34.50	4.15
Chloride of sodium,	...	...	...	0.56	3.71	0.45
Chloride of potassium,	...	...	...	0.26	...	...
Sulphuric acid, ...	0.17	...	1.46	0.83	4.91	0.93
Silica, ...	...	...	0.17	64.50	...	1.31
Quantity of oxygen of the bases that are combined with phosphoric acid,	12.35	11.92	11.97		11.18	

As regards these analyses, it must be remarked, that the re-

sults obtained by Fresenius and Will, Bichon, Thon, and Boussingault, from peas grown on entirely different places, present, with tolerable stability, a proportion of about 34 per cent. of phosphoric acid, part of which, however, is derived from the phosphorus that exists in the protein compounds of the peas. The potash varies from 34 to 39½ per cent., while the soda, lime, and magnesia, are inversely as the quantity of potash. The quantity of oxygen in the bases of the ashes of peas varies from 11.18 to 13.51 per cent. The quantity of sulphuric acid is partly produced by the oxidation of the sulphur of the protein compound.

The following table presents a beautiful view of the inorganic constituents of some parts of plants that are used as food. Regarding the phosphoric and sulphuric acids, I repeat the same remarks which I have just made. This table has been taken from the analyses published by Fresenius and Will.

	Vicia faba Bichon	Phaseolus vulg Thon.	Barley. Bichon.	Oats. Boussingault.	Acorns. Kleinschmidt.
Potash,	20.82	21.71	3.91	52.9	64.64
Soda,	19.06	21.07	16.79	..	..
Lime,	7.26	5.38	3.36	3.7	4.89
Magnesia,	8.87	7.35	10.05	7.7	5.57
Oxide of iron,	1.03	0.34	1.93	1.3	..
Phosphoric acid,	37.94	35.33	40.63	14.9	15.62
Chloride of sodium,	..	3.32	..	..	0.98
Sulphuric acid,	1.34	2.28	0.26	1.0	...
Chlorine,	1.45	...	..	0.5	..
Silica,	2.46	1.48	21.99	53.3	0.96
Phosphate of iron,	..	..	..	..	2.61
Sulphate of lime,	..	..	..	...	4.73
Quantity of oxygen in the bases,	13.56	13.04	11.70	14.95*	

A considerable difference exists between these results and those mentioned by Johnston (Elem. of Agric. Chem.),† where

* Harting has published analyses of ashes of other kinds of plants. (Ann. der Chem. und Pharm. April 1843, S. 97). Others may also be found in the number for June 1844.

† This and the succeeding references are to the first edition of my *Elements*, the only one translated into the Dutch. The table of analyses here introduced by Mulder, is compiled from the results of Sprengel, the best we at that time possessed. The reader will find far more ample and correct information on the subject of the inorganic constituents of plants in the second edition of my *Lectures*, p. 365 to 438. —*J.*

it is stated that in 100 parts of ash of the following plants, are contained :—

	Wheat.	Wheat straw.	Barley.	Barley straw.	Oats.	Oat straw.	Beans.	Bean straw.
Potash, ...	19.	0.5	12.	3.5	6.	15.	19.5	53.
Soda, ...	20.5	0.75	12.	1.	5.	trace	38.	1.5
Lime, ...	8.	7.	4.5	10.5	3.	2.75	7.75	20.
Magnesia, ...	8.	1.	8.	1.5	2.5	0.5	7.5	6.75
Alumina (l) ...	2.	2.75	1.	3.	0.5	trace	1.5	0.5
Oxide of iron, ...	...	...	trace	0.5	1.5	trace	...	0.5
Silica, ...	34.	81.	50.	73.5	76.5	80.	6.	7.
Sulphuric acid, ...	4.	1.	2.5	2.	1.5	1.5	4.	1.
Phosphoric acid,	3.5	5.	9.	3.	3.	0.25	13.75	7.25
Chlorine, ...	1.	1.	1.	1.5	0.5	trace	2.	25.*

It is peculiarly worthy of notice, that these inorganic constituents are not diffused regularly through the plant, being accumulated in some parts much more than in others. This indicates a connection between the organic and inorganic constituents of plants which in the highest degree deserves our attention. Johnston mentions the following proportions (Elem. of Agric. Chem.) :—

Proportion of ash in 1000 parts of

Oats	...	38	Oat Straw	...	60
Beans	...	30			
Peas	...	28	Pea Straw	...	50
Barley	...	20	Barley Straw	...	50
Indian Corn	...	15	Straw of Indian Corn		50
Rye	...	10	Rye Straw	...	30
Wheat	...	12	Wheat Straw	...	50

These results indicate not only that different plants contain a different quantity of inorganic substances, from which again a different mode of culture is necessary,—but also, that the productiveness of the soil will not become greater by imparting to the plants an abundance of inorganic constituents. In rye and wheat, for instance, the proportion of straw may thus be increased, without either the number or the weight of the grains becoming greater. Johnston remarks that this proportion of ash in the straw increases in proportion to the distance from the root ; in such a way, that when the undermost fourth part of the straw of wheat yields

* In Payen's work, entitled Mem. sur les Developpemens des Vegetaux, p. 318, other determinations of the inorganic constituents of plants may be found.

3 to 4 parts of ash, the second fourth will give 5 to 6, the third 6 to 7, and the uppermost 8 to 9 parts. Oat and rye straw, on the contrary, contain the largest proportion of ash in their undermost part.

Similar determinations have recently been made by A. Vogel, yr., (Annalen der Chemie und Pharmacie, Juli 1844, S. 139). He has analysed the ash of the stem, leaves, and fruit of Pyrus spectabilis, and his results were the following:

	Stem.	Leaves.	Fruit.
Alkaline carbonates, ...	4.6	...	29.
Sulphate of potash, alkaline phosphates, and traces of common salt,	...	6.8	...
Alkaline phosphates, ...	...	...	14.1
Carbonate of lime, ...	82.2	72.9	37.
Carbonate of magnesia, ...	4.9	9.76	5.52
Phosphates of lime and magnesia,	8.8	10.50	18.60
Silica, ...	...	...	3.70
	100.5	99.96	97.92

These analyses confirm what I have said before (p. 634,) that it is impossible that a whole plant, wherever cultivated, should contain such a proportion of inorganic matter that its quantity of oxygen should be constant in the same species. It would further appear, that the small quantity of common salt and sulphate of potash which has been found in the leaves, has escaped observation in the analysis of the stem; for how could they have reached the leaves unless through the stem?

The large quantity of alkaline phosphates in the fruits, and the large proportion of phosphates of lime and magnesia which they contain, compared to that in the stem and the leaves, is evidently connected with the quantity of sap in the fruit. Whatever other value these analyses may possess, they teach us, properly speaking, nothing that may be used for science. If either the stems or the leaves had contained an equal quantity of vegetable sap with the fruits, the analysis of them would evidently have differed much less than they now appear to do.

It must be acknowledged, that the analyses of ashes from various parts of oak trees, which de Saussure made a num-

ber of years ago, are of much more scientific interest than any of those which we have mentioned. Their results will be seen in the following table :—

	1000 parts of the			100 parts of ash contain					
	Fresh plant contained of ash.	Dry plant contained of ash.	Fresh plant contained of water.	Salts soluble in water.	Phosphates.	Carbonates.	Silica.	Metallic oxides.	Loss.
Oak leaves of 10th May,	13	58	74.5	47	21	0.12	3	0.64	25.24
Do. of 27th Sept.,	24	55	54.9	17	18.25	0.23	14.5	1.75	25.5
Branches from which the epidermis was removed,	...	...	...	26	28.5	12.25	0.12	0.1	32.58
The bark of these branches,	...	60	...	7	4.5	63.25	0.25	1.75	22.75
The middle or hardwood,	...	2	...	38.6	7.5	32.	2.	2.25	20.65
The new wood,	...	4	...	32	24	11	7.5	2.	23.5
The bark of the trunk,	...	60	...	7	3	66	1.5	2.	31.5
The epidermis of the bark,	...	73	...	7	3.75	65	0.5	1.	22.75
Extract of oak wood,	...	61	...	51	...	...	...	...	...
The soil in which this oakwood was grown,	...	41	...	24	10.5?	10	32	14.	3.5
The extract from that soil,	...	111	...	66	66	...	...	...	...

The following statements by Johnston, (Elem. of Agric. Chem.), show how large a quantity of inorganic constituents is extracted by plants from the soil, and consequently removed from the land. In a crop of four successive years, during which the produce amounted per acre to—

The first year ; turnips, 25 tons of roots and 7 tons of tops.

The second year ; barley, 38 bushels, of 63 lbs., and 1 ton of straw.

The third year ; clover and grass, 1 ton of each, in hay.

The fourth year ; wheat, 25 bushels of 60 lbs., and $1\frac{3}{4}$ tons of straw :

The quantity of inorganic matter removed from the soil amounted to—

Potash,	...	. .	281 pounds
Soda,	...	...	130 ,,
Lime,	...	...	242 ,,

Magnesia, ...	...	42 pounds
Alumina, (?)	...	11 „
Silica, ...	...	318 „
Sulphuric acid,	...	111 „
Phosphoric acid,	...	66 „
Chlorine, ...	...	39 „
In all,		1240

Each of the plants here named extracts from the soil its own quantity and kind of constituents, and it follows from this, that when certain ingredients have been taken from a soil by the culture of a certain crop, this soil may afterwards very well serve for the cultivation of another kind of plant, which the next year can actually yield an abundant produce. Another consequence of this difference in the several ingredients required by each individual species is, that as far as the rain water, ascending by capillary attraction, cannot replace these inorganic substances in the upper soil which have been removed from it, they must be added to it;—and this is especially the case with the phosphates, which are not present in ordinary water. Finally, it appears from the fact mentioned, how advantageous it is for a soil, that the roots and other unused parts should be ploughed in; for in this way, not only the organic, but also the inorganic constituents which these contain, are preserved in the soil, and may thus serve as food for succeeding plants.

From what has been stated here, it will be easily understood why forced and hothouse plants cannot duly develope themselves, and but rarely produce fruits. They are in want of salts, which they ought to derive from the soil, and thus they are deprived of a most important necessary of life. It is for the same reasons that our heath soils are so unproductive; and they might be converted into fertile land, if the upper soil could be mixed with clay, for the inorganic substances that are laid upon the top would be less rapidly carried down by heavy rains, and consequently the upper soil would be less easily deprived of its inorganic constituents.

In conclusion, if we look at the purposes served by the

inorganic substances in plants, we perceive in the first place that several organic substances have to be combined with determinate proportions of certain bases. We know that the fibrin and albumen of the blood require carbonate of soda, in which they are dissolved, and with which they are chemically combined; further, that soda always exists in bile, and that phosphate of lime seems to be in chemical combination with gelatine in bones. In the same manner, a number of vegetable substances that exist in plants most probably acquire the peculiar character which they thus possess, from their not being present there as pure organic bodies, but combined with inorganic substances. On this subject I refer the reader to page 384; and I believe we must regard the inorganic bases in plants as serving much more extended purposes than merely neutralising the free acids present in them. It appears to me that these very inorganic constituents are the causes of the differences which exist between the same organic substances in different plants, by which not only different plants, but also different parts of the same plant, are enabled to exhibit such an unlimited variety.

In this department of science, however, little only can at present be fully explained with regard to the peculiar service of each salt or base. In this respect our knowledge is still most defective. Perhaps the following remarks will not be considered superfluous, especially as regards the purpose of these substances in plants which are used as food for animals.

The sulphur and phosphorus which exist in combination with protein, and of which the different proportions impart to this substance such a difference of character in the animal body (p. 306), are also present in plants, although in proportions different from those in animals. The manner in which these two elements are produced, may be explained from a generally acknowledged principle. This principle is: that in the vegetable kingdom there exists a tendency to de-oxidation. If—and this does not admit of any doubt—the action of certain substances in plants can deprive the carbonic acid of part of its oxygen, whilst the remaining compound enters into combination with the elements of

water, then several other bodies may and will lose oxygen through the same influences.

It is unquestionable that the sulphur and phosphorus are to be traced to the sulphates and phosphates, and consequently the presence of sulphates and phosphates in the soil is indispensable for the production of these organic combinations with sulphur and phosphorus (protein compounds)—a fact which has been long known from extensive experience.

I have several times remarked, that it appears to be an erroneous idea that these vegetable protein compounds should pass into the animal body without undergoing any change. Being produced in plants along with other bodies containing sulphur,—oil of mustard, &c., for instance—they may be subsequently deprived of sulphur and phosphorus, with which they may be again combined within the animal organism. We find an instance of this in taurin, which, according to Redtenbacher's analysis, contains 26 per cent. of sulphur, and which is, beyond all doubt, formed by the animal body itself. Besides, in hair, in the nails, and in the epidermis there exists a much larger quantity of sulphur than in the protein compounds.

It would appear, therefore, that both plants and animals have the power of decomposing sulphates, and—as is shown in the fats of the brain—phosphates also.

The whole of the animal food is, however, originally derived from plants, and it is therefore an essential requisite for the organic kingdom, that the soil should contain sulphates and phosphates, to assist in the formation of these protein compounds. The animal body carries along with it an abundance of phosphates in its bones, and in almost every one of its constituents. We find phosphate of lime in combination with fibrin and with the albumen of the serum of the blood. Edible plants must therefore be capable of supplying a sufficiency of phosphate of lime to the animal body. The same salt exists in considerable quantities in wine and milk, and from this again we conclude, that the vegetable food of a cow, for instance, ought to contain a large quantity of phosphate of lime.

In some of the corn plants, this salt exists in very large quantity. All soils, therefore, in which these plants are to be cultivated, must either contain abundance of these phosphates, or they must be supplied in the form of manure, in the same proportion in which they are extracted from the land. Hence the utility of applying bones as manure to peas and beans, corn plants, cabbage, beetroot, turnips, and other plants, which, along with a large quantity of albuminous substances, contain much phosphate of lime—the former being always accompanied by the latter.

There can be no doubt as to the manner in which inorganic salts, such as phosphate of lime, are absorbed by the roots of plants. The salt must be completely dissolved before it can enter into the plant. We have shown in the fifth chapter, that certain acids—such as the acetic, the formic, &c.—by which every basic phosphate of lime can be dissolved, are actually present in the soil. Carbonate of lime also may thus be dissolved by water containing carbonic acid, and absorbed by the cells of the roots; and in a similar manner other insoluble substances in the soil may be brought into a state of complete solution, since they are not surrounded merely by water, but by a very complex liquid.

Among the bases which are present in plants that serve as food for man and animals, oxide of iron is also essential, for it is a constituent of the colouring matter of the blood. The quantity of iron that is required for this purpose is very small. Edible plants contain small quantities of it, and therefore it must be present in the soil. It is present in different proportions in the same kinds of plants, grown on different soils. It is very easy to discover from the ash, for instance, whether a specimen of tea was grown in China or in Java. The soil of Java contains much iron, and thus a much larger quantity of this substance has passed into the tea, than could take place on the calcareous soil of China. The ash of the former kind of tea is therefore of a deep red, and that of the latter kind of a very pale red colour.

With regard to the inorganic substances essential to them,

water plants resemble those that grow on dry land. They differ with the quality of the water, as the others do with that of the soil. When the seeds of plants growing on dry land are not cultivated, but planted by nature, they will only germinate in those soils in which they find the peculiar inorganic food that they require; the same applies to water plants. This is the reason why the weeds on our shores, which require soda and iodine, cannot live in our ditches or marshes, for potash and chlorine cannot be entirely substituted for soda and iodine. I have remarked at p. 142, that it is for a similar reason that the species of plants in our country are so similar to those of the regions about the Rhine.

It has frequently been asked, if plants do really obtain the inorganic substances that are present in them from the soil, because there are some soils, in which little or nothing of these substances seems to exist. Wiegmann and Polstorff* have solved this question by careful experiments. Seeds of Lepidium sativum, sown in cut platinum wire in a platinum crucible, moistened with pure distilled water, and protected from dust, produced plants, which, on being burned, left the same quantity of ash as an equal weight of the seed. When, therefore, every extraneous source from which inorganic substances could be derived was cut off, the quantity of these substances was not increased.

When seeds were sown in quartz-sand, which had previously been extracted with aqua regia, the result was entirely different. Although the circumstances had in every other respect been the same, the quantity of ash which the plants now left was double that of the seed. It appeared, on analysis, that this quartz-sand, although long treated with aqua regia, still retained 3·1 per cent. of potash, lime, magnesia, alumina, and oxide of iron. When this quartz-sand was kept for a month moistened with water, through which a continual current of carbonic acid was passed, the water dissolved out of it silica, potash, lime, and magnesia. It was thus shown that arid sandy soils, which directly yield nothing either to

* Ueber die anorganische Bestandtheile der Pflanzen. Eine in Göttingen, im 1842, Gekrönte Preisschrift.

water or to plants (p. 134), may yet yield to plants substances soluble in water—by the influence of water containing carbonic acid,—provided they contain those substances. It is most clearly proved by those experiments that the so-called insoluble silicates are slowly decomposed, and that they are subservient to the growth of plants.

With these experiments, performed with different seeds, viz., those of Vicia sativa, Hordeum vulgare, Avena sativa, Polygonum fagopyrum, Nicotiana tabacum, and Trifolium pratense, Wiegmann and Polstorff contrasted others, in which the plants were grown on an artificial soil, consisting of

Sand, ...	861·26
Sulphate of potash, ...	0·34
Chloride of sodium, ...	0·13
Sulphate of lime (anhydrous), ...	1·25
Chalk, in very fine powder, ...	10·00
Carbonate of magnesia, ...	5·00
Oxide of manganese, ...	2·50
" iron, ...	10.00
Alumina (precipitated from alum),	15·00
Phosphate of lime, ...	15·60
Humate of potash, ...	3·41
" soda, ...	2·22
" ammonia, ...	10·29
" lime, ...	3·07
" magnesia, ...	1·97
" alumina, ...	4·64
" iron, ...	3·32
Insoluble humin, ...	50·00
	1000·00

While the plants grew badly in the quartz-sand which was used in the former experiments, and produced no fruit, in the present mixture, which was moistened with distilled water, and protected from dust, they became well developed, and they left in all, after burning, from four to five times more ash than the seeds originally contained.

The conclusions to be drawn from these comparative ex-

periments, however, are defective, because the quartz-sand was devoid of any organic substance, and of all inorganic constituents which are easily soluble in water. At the same time they show most clearly, that if there is a larger quantity of inorganic substances present in the plants than there was in the seeds, these must have been supplied to the plants from without. We also learn from them, that the quantity of inorganic substances increases with the growth of a plant.

With regard to the service performed by the inorganic food of plants, the reader is referred to the commencement of Chapter VII., p. 382.

E. On the Organic Food of Plants.

When we observe how one organic object attaches itself to another, to extract nourishment from it, we cannot resist the impression, that organic beings support one another.

The parasitic animals which live upon the skin of others, those which lay their eggs below the skin of others to be hatched there, and the entozoa, are among the manifold instances in the animal kingdom, which show that there is a material, perhaps even an organic, mutual connexion between the several individuals.

In the vegetable kingdom, the number of parasites is still larger than among animals. The stems of trees are almost always covered with mosses and lichens. Although it is true that many of these are false parasites, attaching themselves to some organic object merely for the purpose of support, yet a great many of them have no other source of food but the organic object by which they are supported.

Confervæ and other algæ are developed upon gold fishes;* water salamanders and frogs are often covered with confervæ;† confervæ and fungi are developed in the lungs of

* Goodsir in Annals of Nat. Hist., tome ix., p. 333. Unger in Linnæa, tome xvi. p. 120.

† Hannover in Muller's Archiv., 1839, p. 338. Stilling, *ibidem*, 1841, p. 279. Hannover, *ibidem*, 1842, p. 73.

birds;* various simple fungi are deposited upon the human skin,† and are even not unfrequently found on the mucous membranes; and fungi are also found in cells of plants, for instance, in those of potatoes.‡

It appears certain that the plants we have mentioned actually draw organic food from the bodies to which they are attached.

It was necessary that there should exist in nature one source of nutriment common to the great majority of plants; a substance from which plants could extract what they want, and through which any thing in which they might be deficient could be supplied to them. This substance is the soil, at least for by far the greater number of plants that are now in existence. To many others food is conveyed by other means. The little plants just referred to, and those enumerated at p. 94–98, severally feed upon peculiar substances, which are to be extracted from the organs upon which they exist as parasites. The mould-plants that are produced upon different organic substances differ with the nature of these substances, and remain always of the same kind, having a persistence which they could only have acquired by the unaltered nature of the food by which they are sustained. On moist leather, covered with tannate of iron and gum, upon ink, &c., in every place and condition, the same kinds of mould-plants are always produced.

This constant appearance of one and the same mould-plant upon the same organic substance, teaches us not only that these little plants are developed from the organic molecules of the substances on which they are found, but also that they are fed by these substances. Moist leather, for instance, does not putrefy in consequence of moulding, but the original

* J. Müller in Archiv., 1842, p. 198. Deslongchamps in Comptes Rendus, vol. i. 1841, p. 1110. And also various observations in Comptes Rendus, 1841, p. 1110. Philosoph. Magaz. 1833, vol. ii. p. 74.

† Hanover in Müller's Archiv., 1842, p. 281. Schönlein, *ibidem*, 1839, p. 82. Gruby, *ibidem*, p. 22. Bennet, Transact. of the Royal Soc. of Edin., tome xv. p. 2. Annals of Nat. Hist., vol. vi. p. 125.

‡ Martius, die Kartoffel-Epidemie, 1842. Nägeli in Linnæa, tome xvi., p. 288.

production of these moulds arises from the decomposition of the blackening substance. When the plants have been once produced, they feed copiously upon the constituents of the leather, viz., the tannic acid and gelatine, which they exhaust only after a number of years.

The *Merulius destructor* is highly remarkable in this respect. This plant causes in England a loss of millions. Having been once produced upon wood, it propagates itself, forces its threads of mycelium deep into its substance, exhausts it, and makes it at last fall asunder. This destruction has been called in England *dry rot*, and its real nature has for a long time been misunderstood. The investigations of Kyan have first thrown some light upon this subject. A solution of corrosive sublimate, in which the timber is soaked, and which penetrates into it only to a depth of a few millimeters, arrests not merely the spreading of this fearful disease in wood, but prevents it even in the most unfavourable circumstances. When pieces of sound wood, impregnated with this solution, were closely fastened to pieces that were much affected with *dry rot*, and these placed together in pits in which no ordinary wood can remain without becoming rotten (in Woolwich these cellars are called *dry rot pits*), they completely withstood the infection for several months. The surface of the wood had been saturated with a substance which checks the propagation of the plant, and thus arrests the evil.

The threads of the mycelium of this plant (Merulius destructor) penetrate deep into the wood, and the plant is developed and nourished at the expense of those parts of the timber which are the least dry. Like all other plants, it requires protein compounds, and, therefore, it lives upon the albumen which exists in the wood, and also upon the cellulose and other parts. The same organic substance, having lost one form, immediately assumes another. Thus, one plant is decomposed, and another immediately built up from the constituents of the former. The cellulose and protein of the wood are not converted into carbonic acid and ammonia, but from the wood they pass directly into a new organisation, the cellulose being probably first converted into dextrin, or

at least brought into some neutral and semi-soluble form, in which it must be before its molecules can leave the wood, and produce with albumen a new series of cells, to assume the appearance of Merulius destructor.*

The manner in which the corrosive sublimate acts in counteracting this dry rot, shows most clearly, that putrefaction or decay, properly so called, is not here checked, but only that the *spreading* of the plant, which takes place over the surface, is stopped. It is the new plant, therefore, which consumes the wood, but not the decaying wood which produces the plant. This being thus clearly proved, the production and spreading of the Merulius destructor, and the destruction of the wood by this plant, afford an instance, not only of a plant feeding upon other substances than carbonic acid and ammonia, but also of the direct production of a plant from organic substances. This is a striking instance of a simple transition of the cellulose and protein from one individual into another.

I consider this instance as one of much importance, and, therefore, I shall mention one or two others which are to be explained on similar principles.

Unger has communicated important observations on parasitic plants.†

When a parasite is in its most simple form, its vascular tissue passes directly into that of the parent plant. This cannot be explained in any other manner, than that the parasite is directly nourished with prepared vegetable sap. But Unger describes a great number of other forms, which are unquestionably nourished in the same way.

The parasites that are especially suitable as illustrations of our present subject, are those of which part of the vessels are joined by their apertures with those of the parent plant (Sarcophyte, Ombrophytum, &c.); those that form a tap root, of which the fibres adhere to the parent plant (Langsdorfia); those which have no tap root, but a great number of roots which are connected with the parent plant (Lathræa squa-

* By the kindness of Dr. Faraday, I have had ample opportunity of becoming acquainted with this plant.

† Wiener Archiv., für Naturgeschichte, t. ii. 1840.

maria); and, finally, those that have long roots, extending either over or below the bark of the parent plant, and thus extract their food from the latter (Viscum, Misodendron, and the greater part of the Loranthaceæ). This food is of an organic nature, previously prepared by the plant, and certainly not carbonic acid and ammonia.

These plants, therefore, are well worthy of attention, because, being dicotyledons, and undoubtedly feeding exclusively upon organic matter, they afford direct proof, that it is perfectly possible that plants fixed in the soil may absorb organic food, if this is present in the soil.

According to Schwabe,* the Boletus destructor is fed in the same manner as the Merulius destructor, viz., by extracting its food from the wood, and thus making it fall asunder. He thinks that the Merulius vastator attracts moisture from the air through its fibres, and thus causes the wood to putrefy. The latter opinion, however, cannot be maintained, because, when the wood has no fungi upon its surface, and is then moistened with water, it decays far less rapidly than when fungi are present. Consequently the attraction of moisture cannot be the sole cause of the decay of the wood, but this decay is to be ascribed to the extraction of substances from the wood, effected by the fungi.

We might quote a great many other instances of plants, that actually feed upon organic substances which have not been transformed into humus—plants that are very far from living upon carbonic acid and ammonia.† But those already mentioned may suffice to show, that there are some plants which do actually increase in size by the absorption of organised substances, which have been merely isomorphically transformed in a retrograde order, to be afterwards transformed once more, in a progressive order, and to produce new cellular systems.

Though these are undoubted facts, it is on the other hand equally true, that there are real atmospheric plants, which

* Linnæa, 1840, p. 194.

† For instance Mater aceti, which is produced from acetic acid and protein, which are present in vinegar. Scheikundige Onders. Deel 1, p. 539.

have either no support at all, or only one from which they can obtain neither organic nor humic food; for instance, a great number of lichens, especially such as live upon rocks, some orchidaceæ, &c. (see p. 109).

It is far from surprising, therefore, that there should be a third class of plants, that absorb not only carbonic acid and ammonia, but also organic food—humous substances, which occupy an intermediate place between organic substances on the one side, and the constituents of the atmosphere on the other (p. 132). To this third class the majority of existing races of plants belong, and their existence depends upon the layer of humus, which in many places covers the earth to a certain depth, in the present period of its history. Before that layer was formed, the now living plants did not exist; and whenever that layer again disappears, either in consequence of a change in the atmosphere or through other influences, then the greater part of the present phanerogamic plants will at the same time be destroyed.

In this point of view, it appears that a satisfactory answer may be given to the question that has been so partially treated, whether or not plants absorb from the soil organic food along with carbonic acid, water, ammonia, and ammoniacal salts? Some plants do not absorb organic food; others live upon it entirely; others again make use of both organic and inorganic food. To the latter class belong the greater part of the plants now living, viz., those that are rooted in the soil.

I need not detail the reasons which have led some, especially Liebig, wholly to deny that plants absorb organic food. In the first place, many of the constituents of the soil are continually undergoing decomposition, and it *seems*, therefore, as if in their organic state they are not absolutely necessary for plants. In the second place, plants do actually absorb carbonic acid, water, and ammonia, and convert them into constituents of their own substance, whence it *seems* to follow, that they can live exclusively upon these compounds. In the third place, the quantity of the organic constituents of the soil is in most cases so small, that they *seem* to be not

essential. But these and all similar *seeming* reasons are opposed by others, whilst no proof has been advanced for any of those that have been just mentioned, or may still be produced. In the first place, none of the plants here referred to appear to thrive in soils that are entirely destitute of organic substances. As to the quantity of these substances, this is a matter of no consequence, any more than that plants cannot live upon them exclusively. The quantity of common salt required by an animal for its existence is also small, and an animal cannot certainly live upon common salt alone; yet common salt is indispensable to the animal organism. It appears to me, that the organic constituents of the soil are equally indispensable for the organism of plants. Experience has proved it, and against this no denial can stand. The question here is not whether plants may not cause the organic matter in the soil to accumulate, by condensing the constituents of the atmosphere, and whether in this way they live upon organic substances. This regards merely the final results of what takes place in the actions of nature. Directly opposed to this is the fact, that an arid sandy soil sometimes requires the lapse of centuries to produce a few heaths, which grow but poorly, and that when these are ploughed in, that is, when organic matter is mixed with the soil, the latter becomes fit for growing pines; further, that these trees, increasing in size and shedding their leaves, render the soil fit for the culture of buckwheat and rye, and that by thus introducing organic substances into the soil and yearly increasing their quantity, our arid sands may, after a number of years, be converted into a fertile region.

Whilst, therefore, heaths require but a small quantity of organic matter, pines require more, buck wheat and rye still more, to thrive vigorously. It appears to me that the true account of the matter is simply this: plants obtain their food both from the atmosphere and from the soil. The atmosphere must yield the building material for some, whilst for others it must supply the unelaborated mass which has not yet become such a material itself. It is the part of the soil to

render some substances fit to become food for plants; and although plants condense substances *from* the atmopshere, yet there are only a few that live *through* the atmosphere alone.

The great value of this small quantity of organic food to plants is apparent from the effects of such manures as contain a considerable quantity of vegetable matter. We perceive these effects after the ploughing in of the roots of the previous crops,* the digging in of the leaves of trees, the admixture of sawdust, and especially the sowing of clover, rapeseed, and spurry, which are subsequently ploughed in, and many other instances. The practical agriculturist knows well, that organic substances of any kind render the soil fertile, although not all in the same degree, and for this reason he mixes vegetable and animal substances together, thus to increase the amount of organic matter in the soil. In horticulture it is found, that tan, mud from the sea, bran, and similar substances, are excellent food for plants, and every one may easily find this confirmed by experience. For the same reason charcoal may also be called an organic food of plants, because it is finally converted into organic matter.

* Boussingault has examined (l'Institut. 1840, p. 205), what quantity of organic matter is introduced into the soil by the ploughing in of the roots that have been left in the soil by the preceding crop. These experiments derive their chief importance from their indicating how much nitrogen is thus left in the soil, and may at least for the greater part be supplied to the succeeding crops; but they enable us in the second place to calculate how much ulmic and humic acids, &c., may be formed in the soil by the decomposition of these substances.

He found that on a hectare (about 2½ imp. acre,) upon which wheat had been grown, 1036 kilogrammes (about 2300 lbs.) of stubble and roots were ploughed in; of clover the quantity amounted to 1547 kilogrammes, and of oats to 650 kilogrammes. A hectare of soil thus receives the following quantities of

	From Wheat.		Clover.	Oats.
Carbon - -	501.4	kilogram.	671.4	325.7
Hydrogen - -	55.0		82.0	35.1
Nitrogen - -	4.2		27.9	2.6
Oxygen - -	402.8		570.8	253.5
Ash - -	72.6		194.9	33.1

It is not necessary to remark, however, that part of these constituents, especially of the carbon, is given off to the atmosphere.

The meaning of the term *organic food*, however, is far too vague, and requires therefore a little explanation. It is by no means invariably the case, that every organic substance, provided it be soluble, constitutes a useful food for plants; on the contrary, experience shows that the number of substances, fit for this purpose, is but small. They have been enumerated in the fifth chapter. They are produced by the decomposition of the greatest part of organic substances that are yet known, whilst these are in contact with air and water, especially when diffused through porous substances, such as alumina. All these organic bodies are first converted into ulmin, and subsequently into ulmic acid, humin, humic acid, geïc acid, apocrenic acid, and at last into crenic acid. Of these seven substances, the five acids can all be combined with bases, and thus rendered soluble in water. These are the organic substances—and as yet we know of no other that are absorbed by plants as food.* They are present in every soil, and apparently they all enter through the tender roots into the plants, where they are to perform important functions.

The greater part, and perhaps the whole, of the ammonia which plants absorb from the soil is supplied to them by means of these organic acids. Experience has taught us, that salts of ammonia are injurious to plants, unless they are combined with these organic acids, and that when thus combined—as they are in liquid and other manures, in decayed sheeps', cows', or pigeons' dung—they are of great benefit to plants.† Whatever salt of ammonia is added to the soil, it

* Hermann has replied (Erdmann's und Marchand's Journal, 1845) to my remarks upon his experiments (see above, p. 171), but he has not changed my opinion.

† Vegetable and animal manures differ in many respects in their influence upon plants. Before being decomposed, those of animal origin are often injurious, whilst the others are in most cases harmless. Berzelius observed, that farm yard manure and urine, before they had undergone putrefaction, did damage to plants, whilst after putrefaction they acted beneficially. (Hlubeck, die Ernährung der Pflanzen, Prag. 1841, p. 40). Accordingy to Davy, even sugar, milk, &c., when applied in concentrated solutions, are injurious (*ibidem*, p. 40). The cause of the injurious action of animal substances, however, is not only their concentrated form, but that they contain ingredients which act as injurious stimulants upon plants.

can be separated from it from the moment that the admixture has taken place in no other form except in that of ulmate, humate, geate, apocrenate, or crenate of ammonia, provided the soil contains a sufficient quantity of decayed organic matter. Upon this principle, it has been, from the earliest times, the practice of the art of agriculture to bring manure into a state of putrefaction, by which the mixture of the five different ammoniacal salts, just mentioned, is prepared, and food is directly supplied to plants. The urine of men and animals, and guano—that is to say, the urea, uric acid, or hippuric acid which these substances contain, or whatever other substances producing ammonia may be employed—all combine in the form of ammonia with the above-named five acids in the soil, before they serve as food for plants. It is for the same reason that soot, which contains a large quantity of humate of ammonia—the flesh and blood of animals—which are so easily converted into this salt—hair, &c., are such excellent food for plants.

Among the constituents of the soil, there is one which has hitherto escaped attention, although it acts an important part in the changes which the organic substances of the soil undergo. When substances that are completely free from oxygen are mixed with clay or sand—in short, with any of the inorganic constituents of the soil—they resist putrefaction for a long time. We see instances of this in flax, hemp, ropes, wood, all of which resist for a long period the influence of air and moisture. If the falling leaves were so long to remain unchanged, they could be of no advantage to the growth of plants; but they would merely accumulate and raise the level of the soil; whilst, on the contrary, we see them disappear in the course of one year, being converted into humic substances.

As we know by what substances putrefaction is promoted, we cannot have any doubt as to those that promote the formation of humus. They are those organic bodies that are easily brought into a state of decay, when merely exposed to moisture and a certain temperature—viz., in the vegetable kingdom, the albuminous substances, gluten, &c.

These bodies are advantageous to the soil; first, because they yield ammonia, and in the second place, because they produce a chemical change in the substances not containing nitrogen, such as cellulose, woody matter, &c., and convert them into humus.

This is a reason why, by the application of sawdust alone, or other substances containing little nitrogen, which are sometimes used as manures, humus is with great difficulty formed. They are therefore less advantageous for the growth of plants, than when they are previously mixed with protein compounds, such as wool, hair, &c.

Whilst these substances are in a state of decomposition, they sustain the activity of the fibrils of the roots, which are in contact with them (p. 133), and thus the chemical action which is going on in the constituents of the soil is transferred to those of the fibrils.

This peculiarity is worthy of special attention, because it is assumed as a principle, that ammonia ready formed is equally beneficial to plants, as when it is in the nascent state —a supposition which is contradicted by experience.

Now, it may be asked whether these organic substances, being in a continual state of putrefaction, serve merely to yield carbonic acid and ammonia, and thus to communicate to the roots of plants a chemical impulse—a cause of change of materials—or whether the organic constituents of the soil are actually absorbed by plants? This subject has of late given rise to much controversy,* which consisted in my opinion of a mere dispute about words. Science at least has derived but little profit from these disputes, because they have produced only a few new facts. According to de Saussure's experiments, plants do absorb alkaline humates. One of his experiments was as follows (Annalen der Chemie und Phys.,

* Liebig, Die Organische Chemie, in ihre Anwendung auf Agricultur.
Schleiden, Wissenschaftliche Botanik.
Winkelblech, Ueber Liebig's Theorie der Pflanzen-ernährung.
Schleiden, Offenes Sendschreiben an Dr. J. Liebig, 1842.
De Saussure, Ueber die Ernährung der Pflanzen, Annalen der Chemie und Pharmacie, Juni, 1842, p. 275.
Hugo Mohl, Dr. Justus Liebig's Verhältniss zur Pflanzenphysiologie.

June 1842, p. 278). The root of a garden bean was introduced into a tube which was 22 millimetres wide, and 150 millimetres long. This tube contained an aqueous solution of 0.070 grms. of humate of potash, representing 0.018 grms. of humic acid. After a fortnight the weight of the plant had increased from 11 to 17 grms. It had absorbed 135 grms. of liquid, the liquid that had disappeared from the tube being daily replaced by distilled water. The liquid remained clear; the plant had pushed its roots to the bottom of the tube. The root was white, and the colour of the liquid had become much lighter. On evaporating the liquid, 0.020 grms. of humate of potash, containing 0.009 grms. of humic acid, were left behind. One half, therefore, of this acid had disappeared.*

These and other experiments have induced de Saussure to assert that humic acid, when in a state of solution, and combined with alkalies, does actually decrease when plants are growing in it. But this does not prove, in the first place, that the plants were nourished *by it alone*. As the plant, replete with moisture, which de Saussure employed in his experiments, gained 6 grms. in weight, the quantity of 9 milligrms. of organic constituents absorbed in a fortnight is very small. The carbonic acid and ammonia from the atmosphere, which were absorbed by the liquid, might and very likely did contribute to impart to the plant those solid constituents which—although it cannot with probability be ascertained from the way in which the experiment was made—might certainly have been more than 9 milligrms. in weight.

But, in the second place, the decrease in the quantity of soluble humus does not prove that it has been taken up *unchanged*. It is very possible that it was previously decomposed, for instance, into carbonic acid, and that in this state it was supplied to the roots. This is the very point which needs investigation. It must be ascertained whether plants

* Hartig, and afterwards Unger, have asserted (Flora, 1842), that humate of potash is injurious to plants. If this were the case, it would be impossible that any plant could grow at present on the surface of the earth. It is incomprehensible, that when such results are obtained from *experiments*, it should not be clearly perceived that the experiments themselves must be defective.

can take up as food anything else than carbonic acid and ammonia. It has been stated that plants cannot live upon a solution of carbonate of ammonia in water, but this is no proof. A small excess of ammonia may even be poisonous to plants. Besides, it is indispensable to the growth of plants, that part of the food supplied should be given to the roots, as carbonic acid and ammonia, in the nascent state. Finally, it is possible that the presence of organic substances in the soil, although not indispensable for some plants, is absolutely necessary for others.

Every experiment made in a manner similar to those of de Saussure, would thus be liable to objections which cannot be entirely got rid of, because it is impossible to show the presence of humic acid, &c., in the roots of plants. In addition to these experiments of de Saussure, we may refer to others by Wiegmann, showing how important organic food is to the growth of plants.*

He sowed seeds of Nicotiana tabacum and Lupinus luteus in pots, of which one set contained an artificial soil, in which were all the inorganic substances required by the plants, without any organic matter; whilst the other set contained garden mould. The first were moistened with water containing carbonic acid, the second with rain water. The seeds that were sown in garden mould, came up more rapidly, the plants were more developed, and lived longer than those in the artificial soil.

Wiegmann repeated these experiments with various other plants,—such as Caluna vulgaris, Mentha crispa, Polygonum fagopyrum, Lychnis flos-cuculi, Parnassia palustris, and Cardamine pratensis,—and uniformly obtained the same results; namely, that the artificial soil, composed entirely of inorganic substances, and with distilled water alone employed, contrasted strongly as to its effect with that containing humus or organic compounds.

These experiments, however, are open to the same objection as those of de Saussure, since they leave the question undecided, whether the organic food may not first have been

* Botan. Zeitung, 24 Nov. 1843.

decomposed into carbonic acid, ammonia, and water, which therefore, might really have served as food for the plants.

But there are indirect proofs that plants do actually take up and assimilate humates,—that is, humic acid combined in the soil with potash, &c., and especially with ammonia,—and that from these compounds vegetable substances are produced. As such proofs I mention the following:—

1° Plants absorb a variety of saline solutions from the soil, transfer them into their own organism, and assimilate the salts, such as carbonate of lime, magnesia, sulphates, chlorides, silicates, &c. There is no reason, therefore, why they should not also absorb humates, &c., these salts being always present in arable soil.

2° Even solutions of poisons are taken up by plants.

3° Coloured liquids may spread through the whole plant, which may thus have an artificial colour imparted to them—provided the colouring matters are in a state of sufficiently fine division to pass through the cellular membranes.

4° If the dark coloured humates are absorbed by plants—which is probable both from the above experiments, and from 1, 2, and 3—the plants must either be darkened by the colour of the humates, or, if not, the humate of ammonia, &c., must be decomposed, and its elements assimilated by the plant. Now the latter is never seen to be coloured by humates; not even a trace of them can be thus detected in the white roots of plants, whilst a number of colouring matters, in which plants are made to grow, are distinctly perceptible in these roots.

5° Mater aceti, the fungus which forms in vinegar—a plant of which we will treat hereafter—and the plants named before, p. 651–654, are decidedly not nourished from carbonic acid and ammonia, but from dissolved organic food. It being proved that one plant may be produced from other substances, the same is likely to be the case with other plants.

Some of these points require a more detailed consideration. With regard to the first, second, and third, we have seen before, p. 625, that plants absorb all sorts of salts, none of them being excluded, although, according to Trinchinetti

and others, they are not all transmitted in the same proportion. This, however, is not known to be the case with membranes.

Payen has instituted the following experiments regarding the absorption of tannic acid. They deserve particular attention, because this acid is an organic substance, and it being once proved that such a substance can be absorbed, it will be difficult to deny this property to the five organic acids in the soil.

Having remarked, that even a very weak solution of tannic acid is injurious to plants, Payen* specially examined the spongioles for nitrogen, and found that they always contain it in large quantity, so as even to produce an ammoniacal liquid on being submitted to destructive distillation. When, on the other hand, the young roots were deprived of their extremities, they were found to contain so small a quantity of nitrogenous substances, that by destructive distillation they yielded an acid liquid, showing that the quantity of ammonia they produced was insufficient to saturate the acetic acid. This acid reaction became stronger, as the part examined was taken at a greater distance from the lowermost or youngest part of the fibrillæ.

Viewing this in connection with the reaction which tannic acid has upon the youngest extremities of the roots—which are all quickly rendered brown by it—we perceive that these extremities contain a certain quantity of an organic, nitrogenous body, a proof that this body is formed on the spot from the food thus absorbed;—but we perceive at the same time, that tannic acid actually enters into the cells of the fibrillæ of many Rosaceæ, of which the leaves, stems, and even roots, contain tannic acid, and yet these fibrillæ were equally injured by the weak solution in which they were placed, as those of plants in which tannic acid did not exist. Consequently, the extreme fibrillæ of plants which contain tannic acid, are themselves free from this acid. When submitted to destructive distillation, they also yielded much ammonia, and therefore they also contain some nitrogenous body in excess.

* Mémoires sur les Développemens des Végétaux, p. 7.

This shows that the organic food which is supplied to plants, although actually entering *into* the fibrillæ, must, from the very beginning—after having entered into the plant—be elaborated and then transferred to other parts in a soluble state.

Payen obtained the same results from water-roots and air-roots.* I consider these experiments very important. They show that the tannic acid, offered to plants, actually acts upon the protein of the youngest cells of the fibrillæ, in which tannate of protein—a body which readily assumes a brown colour—is produced. This action, and therefore this combination, cannot be effected, unless the tannic acid has penetrated through the cell walls into the contents of the cells of the fibrillæ; that is to say, unless this *organic* substance has been absorbed by the plant. This being the case with *injurious* organic substances, as proved by this experiment, it will warrant the inference that the same may take place in the case of the natural constituents of the soil.

It would be very singular, indeed, if the organic constituents of the soil could not possibly enter into organic bodies, and if the property of penetrating through vegetable membranes (cell walls) belonged only to inorganic substances. I should have to apologise for detaining my readers with these arguments, but that the idea just mentioned is adhered to by many, on the ground of an unproved statement of Liebig's; and many authors, as if carried along by a powerful stream, and having apparently never for one moment considered the subject, blindly repeat the same theory, as if they could by their repetitions silence and contradict the eternal truths of Nature.

Those who persist in arguing that it has not been directly proved that humates, &c., do enter into plants, show by so doing that they wish to shield themselves behind the impossibility, of proving these facts in a so-called direct way. If it is a

* The nitrogenous substance was coloured by nitrate of protoxide of mercury; by the action of boiling water it became white and opaque. It is soluble in potash, and after having thus been removed from the tissue, the latter has undergone no perceptible change. Hence it would appear, that this substance is not an essential constituent of the tissue of the extremities of the roots.

fact, that the sulphurous acid, which is disengaged in a manufactory of sulphuric acid, contributes to the formation of the latter acid, then it is also a fact, that the organic substances in the soil contribute to the formation of plants.

The rapidity with which the humates, &c., are decomposed and converted into other substances, as soon as they have entered into the plants, must be the cause why their presence cannot be proved, like that of tannic acid. Since the humates, &c., are a *universal* food for plants, they must necessarily in every particular plant give rise to particular productions, which differ from the humates, &c., in the same manner as food differs from that into which it is converted. The non-existence of ulmates, apocrenates, &c., in plants, is the very reason why they are to be called food for plants,—a name which it would be wrong to give them, if they could be traced in plants unchanged.

The facts that have here been mentioned, lead to the conclusion, that although plants absorb carbonic acid and ammonia through the soil, the organic salts, soluble in water and alkalis, are likewise taken up *by* plants and changed *within* them. To this property ammonia owes its great fertilising power. Being very easily condensed in the soil, it is fixed by the layer of humus. This takes place in small quantities at a time, whilst the ulmates, geates, humates, apocrenates, and crenates of ammonia, potash, &c., are no sooner formed than absorbed. Hence it is, that a soil, rich in ulmic, humic, and geic acid, can yield but little ammoniacal salt to water. And the reason why animal manures, especially urine, meat, &c., are so valuable for the nourishment of plants is, that they yield to the latter not only ammonia, but at the same time humic acid ($C^{40}H^{12}O^{12}$).

It is now proper to call attention to an important service performed by the organic constituents of the soil in combination with ammonia. It is now ascertained that within plants organic groups are frequently re-arranged and converted into other compounds. If such organic groups are already found in the food, they will more readily give rise to a complex combination, than when the latter is to be

produced from carbonic acid, water, and ammonia. Protein is found in the very extremities of the roots. This protein is formed directly from the food that has been absorbed from the soil. If the untangible ghostlike principle (vital force), which is here so very eagerly introduced, is set aside, we can only have recourse to the mutual action of the particles of matter, to account for the active cause which is at work in these extreme parts of the roots. If we further introduce a principle, which is generally acknowledged as operative in the conversions of matter in the vegetable kingdom, viz., a tendency to disengage oxygen from its combinations, we are able to form such an idea of the way in which this protein is produced in the extremities of the roots, as cannot be far removed from the truth. It may be represented as formed from humic acid and ammonia, although I cannot give this view as the real one, because I have not yet seen protein produced in such a way.

One equivalent of humic acid, four equivalents of water, and five equivalents of ammonia, could produce one equivalent of protein; whilst four equivalents of oxygen would be disengaged.

	C	H	N	O
1 Equiv. of humic acid,	40	12	—	12
5 Equiv. of ammonia,	—	15	5	—
4 Equiv. of water,	—	4	—	4
1 Equiv. of protein,	40	31	5	$12 + O^4$

Now an absorption of humate of ammonia by the plant does actually take place, and the elements of this compound are re-arranged there. The mode of conversion just represented, or some analogous one, is really worthy of consideration.

In a still more simple way, we may explain the formation of the so-called indifferent substances, of which the great bulk of a plant consists, viz. cellulose, starch, gum, and sugar.

Let us take, for instance, starch, $C^{12} H^{10} O^{10}$. When this is to be formed from humic acid, it simply needs to combine with the elements of water, as both substances—starch and

humic acid—contain oxygen and hydrogen in the ratio in which they form water. It being duly proved that the five organic acids of the soil enter into plants, the formation of many substances may indeed be more distinctly traced than can be done in regard to many organic substances not found in plants.

There can, however, be no doubt that these conversions are sometimes attended by a more complex change of materials. We must, moreover, take into account the crenic and apocrenic acids in combination with ammonia and other bases, producing salts which are soluble in water, and which, therefore, *must* be taken up by plants. Consequently, in adopting the scheme by which I have represented the formation of protein, we require to be equally cautious, as when adopting, as is now done, that by which the decomposition of amygdalin under the influence of emulsine is represented.

It may be taken as an unquestionable fact, that if we fix our attention exclusively upon carbonic acid and ammonia, we overlook part of the means, which experience has shown beyond doubt to be employed by nature in the maintenance of the vegetable kingdom.

The difference in the nutritive qualities of different soils is undoubtedly in great part owing to the kind of ulmic, humic, or geic acid, which they contain. Peat, which is so rich in humus, is almost unfit to be food for plants; and yet it consists either of ulmic or humic acid. If its natural decomposition and subsequent conversion into carbonic acid are beneficial, turf ought to be very useful as food for plants, either alone or mixed with nitrogenous substances. But this is not the case, although turf condenses ammonia; and hence it follows that neither carbonic acid and ammonia only are always sufficient, nor that every kind of humic acid is adapted for the nourishment of plants. With regard to the insoluble organic substances which are present in the soil, viz., humin and ulmin, they are gradually converted into the soluble ulmic, humic, geic, apocrenic, and crenic acids (Chapter V.) by successive decompositions. When arable soil is thoroughly washed with water, so as to free it from every soluble ingredient,

and is then kept for some time, it has again acquired substances soluble in water, and also ammonia.

I have still the final remark to add, that I have frequently observed how very rapidly mould plants are produced in moist humate of ammonia, showing that this substance surpasses many others in the faculty of supporting vegetation; and that, therefore,—keeping out of view the way in which it does so,—its presence in the soil is by no means unimportant as regards the growth of plants.

When we consider the chemical composition of those plants which could not derive any nutriment from the soil—many varieties of lichens, for instance,—we perceive that they do not contain a large quantity of nitrogenous substances. This is an additional support to the assertion, that although the nitrogen is usually supplied to plants in the form of ammonia, it is not as carbonate, but either as humate, or as crenate or apocrenate of ammonia; for these lichens could, like every other plant, absorb carbonic acid and ammonia from the atmosphere.

I have instituted some experiments in regard to the nutritive qualities of the several constituents of the soil.* It is difficult, however, to make experiments, with the view of investigating whether the organic constituents of the soil are taken up by the plants unchanged. This arises chiefly from the difficulty of supplying the plants, with which the experiments are made, with the same quantity of food, and when there is either too much or too little, the results obtained admit of no mutual comparison.

A number of glass vessels, all of the same size, were placed in an uninhabited and secluded apartment, not exposed to any exhalations. Five of these were filled with coarse sand, which had been previously well washed; and five more with a mixture of the same sand and one per cent. of common wood ashes. Other sets, each of five, were filled with this latter mixture, to which was added besides five per cent. of different constituents of the soil, or at least of such as were of sufficient importance to be experimented with. The con-

* Scheikundige Onderzoekingen, D. II. p. 190.

tents of all the vessels were kept moist by adding pure distilled water.

In each set of five vessels I sowed—

No. 1. Brown beans.
No. 2. White beans.
No. 3. Green peas.
No. 4. Barley.
No. 5. Oats.

They were allowed to grow for one month, from 16th May till 16th June, and then the following results were noted with regard to the development of the several seeds:—

1st set. Sand and rain water.

The seeds had grown very poorly; the plants hardly attained the height of 4 inches. A month later they had nearly all withered.

2d set. Sand, ashes, and rain water.

No. 1 did not grow. No. 2 very much behind. No. 3 tolerably developed. No. 4 very imperfectly. No. 5 a little better, but still imperfectly.

3d set. Sand, ashes, and ulmic acid from sugar, with distilled water.

No. 1 grew imperfectly. No. 2 pretty well. No. 3 very well. No. 4 did not grow. No. 5 very well.

4th set. Sand, ashes, and apocrenate of ammonia from sugar, with distilled water.

No. 5 was the only one that grew, although very weakly.

5th set. Sand, ashes, and humate of ammonia from garden mould (ammoniacal extract of humus), with distilled water.

None had grown.

6th set. Sand, ashes, and humic acid from garden mould, with distilled water.

No 1 grew very beautifully. No. 2 did not grow. No. 3 imperfectly developed. No. 4 did not grow. No. 5 pretty well developed.

7th set. Sand, ashes, aqueous extract of humus, with distilled water.

No. 1. 2. 3. and 5 did not grow. No. 4 imperfectly.

8th set. Sand, ashes, and ulmate of ammonia from sugar, with distilled water.

No. 1, 2, 3, and 5 very beautifully developed. No. 4 imperfectly.

9th set. Sand, ashes, and humate of ammonia from turf, with distilled water.

No. 1, 2, 3, and 5 very beautifully developed. No. 4 did not grow.

10th set. Ordinary soil, in vessels of the same size, with distilled water.

The results were exactly the same as those of the last mentioned experiment.

11th set. Charcoal, previously heated to redness and converted into a coarse powder, with ashes and distilled water.

All the plants grew, but far less developed than in the three last experiments.

When looking at the results of these experiments, and setting aside those substances, which from some cause or other were injurious to vegetation (Exp. 4 and 5), we perceive:

1st. That rain water and atmospheric air are not a sufficient food for plants, because inorganic substances are wanting.

2d. That rain water, ashes, and atmospheric air are likewise insufficient.

3d. That aqueous extract of humus contains too little organic matter to yield to plants what they require.

4th. That ulmic acid from sugar, although it contains no nitrogen, is actually beneficial to plants.

5th. That humic acid from garden mould is very useful to the growth of plants.

6th. That ulmate of ammonia, both that prepared from sugar and that from the acid of turf, assists the full development of plants.

7th. Finally, that charcoal and ashes are less useful in the growth of plants than either ordinary soil or the substances mentioned under 5 and 6.

Besides the reasons mentioned before, and also at p. 113, to prove the utility of the organic constituents of the soil, I have to speak of one more which is of the highest importance, viz., the production of ammonia from the constituents of the atmosphere,—a combination of the elements of the atmosphere, which is but slowly effected without the aid of

vegetation, but which, when assisted by it, takes place with great energy in the ulmic and humic bodies. This is decisively proved by the following experiment:—It was made with beans, which had germinated in an atmosphere void of ammonia, and grown in ulmic acid, prepared from sugar, and also free from ammonia, and in charcoal, both being moistened with distilled water, free from ammonia. The ulmic acid and the charcoal were severally mixed up with 1 per cent. of wood ashes, to supply the germinating plants with inorganic substances (Scheik. Onderz. Deel II., p. 185). I determined the proportion of nitrogen in three beans, and also in the plants that were produced by three other beans. The results were as follows:—

	White beans in ulmic acid.		Brown beans in charcoal.	
	Weight.	Nitrogen.	Weight.	Nitrogen.
Beans,	1.465	50. cub. centim.	1.277	27. cub. centim.
Plants,	4.167	160. c. c.	1.772	54. c. c.

The white beans, therefore, whilst growing into plants in substances and an atmosphere, both of which were free of ammonia, had obtained more than thrice the quantity of what had originally existed in the beans; in the brown beans the original quantity was doubled.

One of the grounds upon which Ingenhousz, and after him Liebig, assumes, that organic substances cannot be absorbed as such by plants, requires particular consideration. It is, as I have mentioned before, that the humic substances in the soil, by taking up oxygen, are completely converted into carbonic acid, and that consequently organic substances *cannot* be supplied to plants. I have not been able anywhere to find either an experiment or an observation, to prove that this is a fact, and there is no reason whatever to assume that the organic salts soluble in acid,—viz., ulmates, humates, geates, apocrenates, and crenates of ammonia, potash, soda, &c., could not yield carbonic acid, and at the same time, whilst in a soluble state, be absorbed by the roots of plants. The one does not certainly exclude the other.

The reasons that can be deduced from the observations of de Saussure - viz., that a soil yields a quantity of carbonic acid equal to that of the oxygen absorbed—are, in my opi-

nion, of no value. First, I have shown (p. 172), that de Saussure's experiments cannot be correct; and secondly, they have not been confirmed by other experiments. I shall here mention some of my own, of which the result appears to give a negative answer to the proposed question. They were made with arable soil, ulmate of ammonia (the acid being prepared from sugar, saturated with ammonia, and then evaporated to dryness), and apocrenate of ammonia (the acid was prepared from ulmic acid by means of nitric acid, and saturated with ammonia).

The soil, which contained a large quantity of organic substances that had been completely converted into humus, was moistened with a little water. The two latter ingredients (ulmate and apocrenate of ammonia) were moistened in the same way, and mixed besides with eight times their weight of thoroughly washed quartz sand. Each mixture was placed in a dish, under an inverted tubulated bell glass, which was closed, air tight, with a glass plate. An open bent tube was fixed, also air tight, in the neck of the bell glass. The under part of the tube was placed in mercury, and thus secluded from the air. The experiment was made in August, and the whole left to itself at a temperature of about 62° F., and at a barometric pressure of about 745.7 millimetres.

After the lapse of a fortnight we could perceive in each apparatus that the mercury ascended in the tube, which could not have taken place if the quantity of oxygen absorbed had not exceeded that of the carbonic acid produced. The mercury continued to rise, and after three months it had reached in the apparatus containing the soil a height of 1 decimeter (about 4 inches); in the two others it was a little less. Accidentally, however, I was prevented from longer continuing the whole of these experiments; but that with the soil showed, in the month of July in the ensuing year,—that is a period of eleven months, including three severe winter months,—a rise of the mercury to a height of 166 millim. at a temperature of about 60° F., and a barometric pressure of 754 millim. After the introduction of caustic potash into the tube, the volume of the air in the apparatus fell by 20 millimetres.

I consider this experiment one of much importance. First, it shows the incorrectness of the theory of Saussure, regarding which I stated my doubts at p. 172, viz., that although the soil absorbs oxygen, it yields an equal quantity of carbonic acid instead; it being now proved on the contrary that the soil continually absorbs oxygen.

The amount of oxygen which is thus absorbed by a very small quantity of soil (I estimate the quantity of organic substances which I employed at 3 or 4 grms., and the volume of the bell glass at 3 litres), is indeed astonishing; for 166 is to 745 in the ratio of 1 : 4.5. This shows that if no nitrogen had been absorbed, nearly the whole of the oxygen was condensed in the soil, and only replaced by a small quantity of carbonic acid.

I am now repeating these experiments, and shall revert to them hereafter. They will afford me a fit opportunity still further to confirm my opinion, that nitrogen is condensed in the soil.

C. Carbonic acid, water, and ammonia, supplied by the roots or leaves, and considered as food for plants.

From what has been stated above, it may be considered as proved that plants which are fixed in the soil extract from it both inorganic and organic salts, and that Thomson is incorrect in saying (Annalen der Chem. und Pharm, Mai 1845. S. 234), "It is known that Liebig has proved the fallacy of the opinion, that in the nutrition of plants the humus itself should have any influence, *and that he has settled this point by a reductio ad absurdum.*" We have still to consider three other substances which are of importance to the growth of plants, viz., carbonic acid, ammonia, and water.

We have said enough of the latter substance in the fourth section. There is, however, one point more we have to consider regarding the connexion between water and the growth of plants. We shall not inquire whether it dissolves substances, and thus conveys them to plants as food, nor whether it serves as the primary agent of the change of materials in

plants, and whilst forming various combinations with substances newly produced, eliminates others with which it was combined; but whether or not water is itself decomposed during the growth of plants.

The question, as it is put here—and it is thus asked in the science of the present day—cannot be answered. There can be no doubt, however, as to the fact, that the elements of water enter into combination with organic substances in plants, and thus cease to appear as water; and further, that these new substances are again capable of undergoing decomposition, that they can give off oxygen, and thus cause the hydrogen, which was originally derived from the water, to remain behind in the plants. That this is actually the case, is apparent from the ethereal oils, resins, &c., if we merely calculate the amount of the various nutritive principles which are supplied to plants.

It follows from experiments of Chevandier,* mentioned below, that in two forests, of which he analysed the wood, 26 kilograms (about 53 lbs.) of hydrogen per hectare (about 2½ acres) are yearly produced from the decomposition of water, and contribute as an organic element to the formation of new parts of plants.

It is placed beyond doubt, by a number of experiments and observations, that carbonic acid actually influences the growth of those plants, which we class with such as absorb organic substances from the soil. Schleiden observed, that in the valley of Göttingen, especially in the basin of the Wehnder papermill, vegetation commences some weeks earlier in spring, and continues later in autumn, than in other parts of the same region. The springs on this peculiar spot contain a kind of water, which is abundantly impregnated with carbonic acid.†

Numbers of similar observations might be quoted, but independent of them, it is an established fact, that the carbon of the wood of forests increases solely from the carbonic

* Ann. de Chem. et de Phys., Febr. 1844, p. 152. The observations of Chevandier regarding the influence of water on the growth of woody plants may be further consulted in Comptes Rendus, 15 Juillet, 1844, p. 167.

† Meyen's Jahresbericht, 1837, p. 26.

acid of the atmosphere, and that the increase of the carbon in plants, growing on a soil which contains but little organic matter, is attributable to the same source. In order to make this quite clear, I shall communicate Chevandier's experiments (*b b*).

He has stated how much wood is obtained from forests where nothing is applied to the soil, and which are cut at regular intervals. From the composition of the wood, the extent of the forests, and the produce in a given period, he has calculated, that from two large forests there are annually obtained, per hectare,

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Ash.
1st forest,	1754 kilogr.	213	33	1507	48
2d forest,	1854	225	36	1586	53

These quantities, which agree with those formerly found by Boussingault (Chevandier calculated the yearly produce of the dry wood to be, per hectare, 3650 kilogrammes), show, among other facts, what an astonishing quantity of carbonic acid is supplied, as the carbon of these forests can only have been derived from the atmosphere. According to these observations, a prism, of which the basis was equal to a hectare, and the summit reached to the extreme limits of the atmosphere, would yearly yield to the wood 1-9th part of its carbon, viz., 1-9th of 16,900 kilograms of carbon * Consequently, if the whole world were covered with such forests, and the carbonic acid absorbed were not reproduced, the atmosphere would, in nine years, have lost the whole of it.

But in the region, to which the determinations of Chevandier refer, vegetation continues only for five months, viz., from the end of April to the end of September, for then the leaves grow yellow. In a period, therefore, of about 150 days, the quantity of carbon condensed from the atmosphere by one hectare of forest, amounts to 1800 kilograms, that is, 12 per day. Taking the average height of each tree at 20 metres (about 23 yards), and supposing there is a perfect calm, the

* The proportion of carbonic acid in the air, is taken at $\frac{6}{10,000}$ part. A prism of atmospheric air, of which the basis is equal to an hectare, weighs 103,300,000 kilograms.

prism of air, of one hectare at the base, and 23 yards high, containing 32 kilograms of carbon,* will lose per day, $\frac{12}{32}$ or $\frac{3}{8}$ of its carbonic acid by weight.

It follows from this, that lofty trees and those which are planted wide that the air may move freely between them, will grow much more luxuriantly than those which are smaller, and planted close together.

The data, therefore, here mentioned, will differ with these conditions, but they will also be modified by the nature of the wood, the region of the earth, and many other circumstances.

But besides the food supplied by the roots, there is still a totally different source of nutriment. It is an undoubted fact, that the parts that become green, absorb carbonic acid, and emit chiefly oxygen in its place. This is actually a two-fold function; for there is no connexion between the absorption of carbonic acid, and the emission of oxygen. The first is an independent function, regulated by the same laws as those which regulate the absorption of gases by liquids; whilst the emission of oxygen is the result of a general chemical conversion of the vegetable substances, to combinations in a lower state of oxidation,—a conversion which the carbonic acid absorbed likewise undergoes. Both these functions deserve our utmost attention. In the next chapter we shall treat of their real nature, confining ourselves at present to prove that the leaves absorb carbonic acid.

The following principle may now be considered as sufficiently established:—*It is the function of the roots to convey to the plants water, ammonia, organic salts, and a small quantity of inorganic salts; but that of the green parts, especially of the leaves, to increase the amount of the non-nitrogenous constituents of plants, by the absorption of carbonic acid, accompanied with an emission of oxygen.*

It is a fact, established of old by the experiments of Sennebier and Spallanzani, but at the same time viewed in connexion with the disengagement of oxygen; that the leaves absorb carbonic acid. This has been further confirmed,

* In this calculation one-fourth of the hectare has been subtracted, to allow for the space occupied by the trees themselves.

especially by de Saussure, and Draper has placed it beyond any doubt by experiments, which will be mentioned in the next chapter. I here assume it as a perfectly established fact.

It is impossible that the quantity of carbonic acid which, according to the experiments of Chevandier above-mentioned, is absorbed by plants to such an extent, that in one hectare (2½ acres) of land about 4000 lbs. of carbon are yearly fixed in the soil, should be supplied to plants *through the soil*, and it cannot therefore be conveyed to them in the rainwater. One litre of carbonic acid weighs 1.98 grms. (about 31 grains.) Rainwater contains only a small quantity of this gas. If we suppose that 1 litre of rainwater contains 10 cub. centim. of carbonic acid * then in 100 litres, there are present by weight, 1.98 grms. of carbonic acid, or 0.54749 grms. of carbon. Consequently, it would require a quantity of 330,000,000 kilogr. of rainwater per hectare, in the course of one year, to supply 1800 kilogr. of carbon. But the quantity of rain-

* Experiments were made in Utrecht, in 1823, with rain water, collected in the month of June in that year, during a west wind. (Commentatio de aquis Rheno-trajectinis.) The result was, that 1 litre or 1000 grms. (35¼ ounces by weight) contained 0.027 grms. of carbonic acid, oxygen, and nitrogen.

One litre of this rainwater, therefore, can contain scarcely 2 cub. centim. of carbonic acid. I have purposely taken five times this quantity in the text.

M. von Baumhauer has, at my request, in July 1845, made the following determinations of the quantity of carbonic acid in five different kinds of rainwater, all of which had been for some time exposed to the air. 1000 grms. contained, at 32° Fahr. and 760 millim. barom. pressure,—

1	2	3	4	5
4.70 cub. centim.	4.24 c. c.	7.98 c. c.	8.58 c. c.	9.09 c. c.

This was in the city of Utrecht. In the country, the amount of carbonic acid will be less. We see, that in every case the quantity of 10 c. c. in 1000 grms. which I have assumed, is large.

The quantity of rain is here calculated for a whole year, whilst in temperate and cold regions plants only absorb moisture from the soil during some months. This again greatly reduces the quantity of carbonic acid that enters the whole root. But, on the other hand, we did not and cannot as yet determine the quantity of dew, which, however, does not penetrate deeply into the soil, but chiefly moistens the leaves. If we suppose the period during which plants absorb water by the roots to be six months, and the quantity of dew that enters the soil to be equal to that of the rainwater, which is certainly much above the actual quantity, then our original calculation remains unaltered.

water that falls in a year on a hectare of ground in the interior of France,* amounts only to 6,500,000 kilogr., and therefore the plants, of which Chevandier speaks, could have received through their roots only $\frac{1}{50}$ part of the carbonic acid which they require, to yield their natural products. I have not taken into account the quantity of carbonic acid present in the absorbed water that penetrates through the soil; but on the other hand a much larger quantity of carbonic acid is lost by the decay of the leaves that are shed, which causes a great disengagement of carbonic acid into the atmosphere; another quantity is lost from exhalation (see Draper's experiments below), whilst a third portion is disengaged into the atmosphere, along with the water that evaporates from the ground.

Proceeding from the experiments of Chevandier, viz., that 1800 kilogr. of carbon are condensed per hectare, 1 litre of rainwater ought to contain not 10 cub. centim., but 500 cub. centim. of carbonic acid, that is, the half of what water can absorb at the ordinary pressure.

This shows most clearly that the greater proportion of carbonic acid is condensed from the air by the leaves, and that only a comparatively small portion is supplied to plants through the rain-water and the soil. Further, that as manures are mixed *with the soil* and act there advantageously, another part of the food, viz., the ammonia and the organic and inorganic constituents, enters into the plants through the roots. It is clear, therefore, that there are actually two sources of nutrition, as was established by the former men of science, and that these two sources enter the plant from two opposite directions, viz., from above downwards and *vice versa*. Those constituents which serve to excite activity within the plant, are drawn from the soil along with the

* According to Kaemtz (Meteorologie, S. 174), the quantity of rain-water that falls yearly on the coasts of Holland and France, amounts to 25 inches, and that in the interior to 24 inches = 0.650 metres. A hectare is equal to 10,000 square metres, which gives 6,500 cub. metres in a year. According to Simons and Greeve (Nieuwe verhandeling van het Bat. Genootsch. 1844) the quantity of rain is for our country (Holland) 0.657 metres, which gives 6570 cub. metres per hectare.

inorganic salts and the water; whilst those which assist to increase the bulk of the plant, and from which, by incessant changes, an almost infinite number of new products is to be procured, are supplied by the atmosphere. There are important peculiarities, which require a further consideration in the next chapter.

According to Chevandier's experiments, the quantity of water which is fixed by plants during their growth is as follows:—1754 kilogr. of carbon, condensed in a year by the wood of the above forests per hectare, and supplied in the state of carbonic acid, were combined with 4591 kilogr. of oxygen. The quantity of 33 kilogr. of nitrogen, found in this wood, was united with 7 kilogr. of hydrogen. The wood contained 213 kilogr. of hydrogen. Deducting from the latter quantity 7 kilogr., we have 206 kilogr. of hydrogen, which require 1650 kilogr. of oxygen to be converted into water. The whole quantity of oxygen contained in the wood, was 1507 kilogr.

Supposing that nothing else has been supplied to these plants than water, ammonia, and carbonic acid, we obtain—

Found in the wood

	C		H		N	O	
	1754		213		33	1507	
C	1754	H	7		H	213–7 =	206
O	4591	N	33		O		1650
CO^2	6345	NH^3	40			HO	1856

From 6345 kilogr. of carbonic acid, 40 kilogr. of ammonia, and 1856 kilogr. of water, a quantity of wood has been formed containing—

C	H	N	O
1754	213	33	1507

The quantity of oxygen contained in 6345 kilogr. of carbonic acid, and 1856 kilogr. of water, is 4591 + 1650 = 6241 kilogr. Subtracting from this the oxygen actually present in the wood, viz., 1507, there remains 4734 kilogr., being the quantity exhaled by the leaves. According to these experiments, therefore, 1856 kilogr. of water have been fixed by one hectare of forest.

It has not yet been proved by experiment, that plants absorb ammonia as such, and this, therefore, is not to be assumed as an established rule in science. Our present knowledge seems to point to the opposite conclusion. The very smallest quantities of ammonia that enter into the soil, are immediately united with the five organic acids in the soil, and form with them salts that are soluble in water, and consequently *must* be absorbed by the roots of plants. These organic acids are wanting in no fertile soil, and must not be wanting. Their quantity is certainly small,—too small to supply the necessary quantity of carbon to plants; but it is large enough to supply them with nitrogen in the form of ammoniacal salts of five different organic bodies.

It requires no demonstration, that if the nitrogen is actually supplied to plants in this form, it is, nevertheless, not a necessary consequence that any ulmic, humic, geïc, apocrenic, or crenic acid should be found in the roots; nay, that the brown absorbed liquid should impart its colour to the white fibrillæ. Not one single cell of the young root is passive during the transmission of the absorbed liquid. Every one of these cells is an active organ, that both undergoes and induces a change of materials.

If we proceed from the established fact that a fertile soil *cannot* contain any free ammonia, but that the latter is immediately combined with one of the five organic acids, always existing in such a soil, then we know, at the same time, that ammonia is never supplied to plants in a free state. It cannot enter the plants in combination with the carbonic acid, which is present in the water of the soil, because this acid cannot decompose ulmate, humate, geate, apocrenate, or crenate of ammonia, whilst, on the contrary, any one of these organic acids decomposes carbonate of ammonia.

All this, I think, sufficiently proves that—provided the soil contains enough of these five acids—the whole of the ammonia which is absorbed by the roots of plants, enters into them in combination with one or more of these acids; and further, that these compounds do not circulate through the plant, but having entered into the extremities of the

roots, are there immediately decomposed and converted into other bodies.

The fallowing of lands, therefore,* during which the weeds are ploughed in, and in general the ploughing in of organic non-nitrogenous substances, increases the quantity of ammonia in the soil, in the same measure as it increases the quantity of humic substances, which powerfully detain the ammonia unaltered, which is subsequently supplied to the next crop. The chief reason, therefore, why the presence of the non-nitrogenous organic substances in the soil is necessary for the growth of plants is, to supply nitrogen in the form of

* The fallowing of lands, as a useful means for increasing their fertility, has been much [illegible]. Some fields never require a fallow, others [illegible] every three or four years. The soil [illegible] though nothing is added to it. The following general rule for [illegible] may be considered as true.

During the [illegible] nothing is taken from the [illegible], on the contrary, supplied [illegible]. Various plant-growth would [illegible] plants have absorbed carbonic [illegible] and formed from the substances new organic products. [illegible] are left [illegible] and [illegible] to the plants [illegible] flowers [illegible] the [illegible] Even this [illegible] by [illegible] the [illegible] the next [illegible] For [illegible] the plants [illegible] would [illegible] the [illegible] [illegible] [illegible]

ammonia. It is, however, evident, that along with this nitrogen, the three other organic elements are yielded at the same time.

A soil which contains no organic matter at all, is destitute of every substance necessary to fix the ammonia, whether the latter be carried into the soil by the rain-water or in any other manner. A soil, for instance, consisting of nothing but decayed feldspar, would, in the event of the falling of rain-water containing ammonia, give passage to a quantity of ammonia proportioned to the quantity of water it allows to pass to feed springs and wells. But when humic substances are present, they immediately combine with the ammonia, and the ammoniacal salts thus produced are retained in the upper layers of the soil by the alumina, &c. (see p. 178) Hence it is, that in places where the soil is fertile, spring water contains hardly a trace of ammonia; whereas, in the absence of organic matter from the upper soil, this water must contain such a proportion of ammonia, as has been either carried into or formed in the soil.

In recent times it has become almost a regular custom to determine the value of manures by the quantity of nitrogen they yield by ultimate analysis. This method is entirely erroneous; for it is based upon the false principle, that by putrefaction all nitrogenous substances are immediately converted into ammonia, carbonic acid, and water. It is a fact that they undergo this change, after having been for years exposed to influences by which decay is promoted. We are, however, not only in the dark as to the number of years that are required by many nitrogenous bodies to yield these products, but we even know with regard to many, that they resist putrefaction for a very long period. Morphine, for instance, is prepared by allowing opium to putrefy; and, what is still more important, the process for preparing leucin, a substance which contains 10.72 per cent. of nitrogen, (Bulletin, 1838, p. 145) is, to bring cheese into putrefaction. Cheese, therefore, does not resolve itself instantly,—not even in a very long time, perhaps not before a number of years,—into carbonic acid, ammonia, and water, but produces a crystalline substance, which contains no ammonia. The same, or a simi-

lar substance, will probably be produced by every other protein compound; and as we do not know either *what quantity* of leucin is thus produced, or whether other non-ammoniacal substances might not also be found, it is clear that the proportion of nitrogen yielded by them is not a proper measure of the value of manures, and that this mode of estimating that value ought to be discontinued.

For this reason most of the estimations of the value of manures made by Boussingault, Payen, and others, are, in our opinion, perfectly valueless.*

* Boussingault and Payen, for instance, have determined the value of manures (Ann. de Chem. et de Phys., Tome 3, p. 65, and Tome 6, p. 449), from the quantity of nitrogen they contain, thinking that this is in a direct ratio to their value. They considered the ammonia that is present as such in the manures, to be their active principle, but at the same time they are of opinion that other substances besides ammonia may be absorbed by plants and supply them with nitrogen. They determined the nitrogen in ninety five different substances, but I omit mentioning the results of this investigation, because they give us no information as to the quantity of nitrogen which these manures can actually yield to plants.

These results are wholly at variance with others of Bouchardat's, who states that carbonate, bicarbonate, hydrochlorate nitrate, or sulphate of ammonia, even when dissolved in 1000 parts of water, act upon plants as violent poisons, and that consequently plants cannot in this way obtain any nitrogen (L'Institut, p. 476, 1843).

Kuhlmann, again, has found results differing from those of Bouchardat, with regard to some salts of ammonia being injurious to plants (Comptes Rendus, 13 Nov. 1843, p. 1115), especially the sesquicarbonate, bicarbonate, nitrate, sulphate, and hydrochlorate of ammonia. He has repeated Bouchardat's experiments, by dividing a piece of ground into separate parts, and moistening each part in spring with a solution of the following substances. The quantity of straw which a hectare would produce has been taken as the general scale of comparison. Where no ammoniacal manure had been applied, he obtained 1000 kilogr. of straw per hectare, and where they had been laid on, the *surplus* produce was as follows:—From sal ammoniac, 1716 (that is in all 2716 kilogr.), from sulphate of ammonia, 1233 kilogr., from nitrate of soda, 800 kilogr., from ammoniacal liquor of a gas manufactory, mixed with hydrochloric acid, 2000 kilogr., from urine, 2240 kilogr., from a solution of glue in water, 2133 kilogr. The latter liquid contained 2½ per cent. of impure glue.

There follows from these experiments, that although nitrogen is supplied from the atmosphere, yet the quantity thus obtained is insufficient for the complete development of plants, which is in relation to the quantity of nitrogen supplied: further, that through the ammoniacal manure the soil receives from the air both more nitrogen and carbon: that the quantity of nitrogen which had been laid on in the form of manure, only once, in spring, was insuffi

The ammoniacal salts do not all assist in the solution of the humic substances of the soil in water. Carbonate of ammonia, for instance, is very effectual in this respect, whilst sal-ammoniac is not. The mere solution of these salts, therefore, cannot be beneficial to vegetation. But the soil contains a variety of bases and carbonates, such as carbonates of potash and lime. Now, when salts of ammonia, sulphate of ammonia, or chloride of ammonium and humic substances, —such as ulmic acid from sugar, which is very sparingly soluble,—are mixed and digested with one of these carbonates—chalk, for instance, and water,—then the acid of the ammoniacal salt combines with the lime, and carbonate of ammonia is produced, which has the power of dissolving the ulmic or humic acid, &c. When sulphate of ammonia, carbonate of lime, ulmic acid and water are digested for some time, a dark brown liquid is obtained, in which a large quantity of ulmate of ammonia is present. A similar result is obtained from a mixture of sal-ammoniac, chalk and ulmic acid, but the liquid contains less ulmic acid.

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cient to produce such a large additional quantity of straw; and finally, that a proportionate quantity of potash, lime-salts, phosphorus, &c., has at the same time been taken from the soil.

Kuhlmann further concludes, that the supposition of Liebig, that rain-water should yield more ammonia to plants than they require, is contradicted by these experiments. He also thinks, that sulphate of potash or lime, and chloride of potassium or calcium, are taken up by plants, because it is certain that sea plants take up common salt. According to him, phosphate of lime and phosphate of magnesia are soluble in water containing carbonic acid.

Similar results have been announced by Schattenmann (*ibidem*, p. 1128), as having been obtained from sulphate and phosphate of ammonia, and sal-ammoniac, with which he has advantageously manured oats and barley. Boussingault thinks (Comptes Rendus, 20 Nov. 1843, p. 1153), that the proportion of chlorine in sea plants bears no relation to the amount of sodium, and that he is warranted in concurring with Kuhlmann's statement, that the salts of ammonia yield to plants carbonate of ammonia, produced by double decomposition by the action of chalk or carbonates of potash and soda.

Chatterley (Phil. Mag. June 1843) has instituted comparative experiments with regard to the fertilising properties of the various nitrogenous salts. He employed for this purpose, sulphate of ammonia, nitrate of soda, and nitrate of potash. His result is, that it may be stated as a general fact, that the nitrogenous salts actually serve as food for plants in proportion as they contain nitrogen.

The manuring of a soil, therefore, with sulphate or hydrochlorate of ammonia acts in this manner, that through the alkaline carbonates in the soil, the ammonia is conveyed to plants as ulmate of ammonia, &c., in a state of solution, and even in this case, the ammonia and the organic acids in the soil assist each other, to serve conjointly as food for plants. Wherever, therefore, a soil contains a large quantity of humic substances, the inorganic ammoniacal salts of the manure cannot as such enter into the plant.

It follows from what I have stated, that even although part of the ammonia in the soil might enter into the plants in combination with inorganic acids, the greater proportion of it is absorbed in combination with organic substances, the latter thus performing a service which is to be considered of the greatest value.

Various substances have been recommended to fix the carbonate of ammonia, which volatilises during the decay of animal bodies that are employed as manures. Schattenmann (Comptes Rendus, 8 Juillet 1844, p. 114, and Annales de Chim. et de Phys. Janv. 1842, p. 116), recommends sulphate of iron, as being of much advantage for this purpose. The products are sulphate of ammonia and oxide of iron, and thus the ammonia is fixed. It is sufficient to spread a dilute solution of sulphate of iron over the manure heaps. He advises the employment of the same compound for excrements, which will have the effect of both fixing the ammonia and removing the disagreeable smell, by the formation of sulphuret of iron. This means would also find useful application in those towns of our country, where these excrements must at certain intervals be removed.

Another substance, which has been recommended for fixing the ammonia, is dilute sulphuric acid, and this has been considered as a useful manure, because a considerably greater portion of ammonia is thus preserved. But the substances that are at present recommended as manures are exceedingly multifarious. A soil which contains the five organic acids mentioned above, requires no sulphuric acid to fix the ammonia.

Daubeny states (Athenæum, 14 Aug. 1841, and Biblioth. Univ. Nov. 1841, p. 410,) that the nitrates of potash and soda are also capable of yielding nitrogen to plants, and must therefore be classed with those substances which are advantageous to some plants. These salts, therefore, must be decomposed either in the plants or in the soil. Both these suppositions are probable, as nitre is found in tobacco and other plants.

Guano, which has been lately so much recommended as a manure, contains a variable quantity of urate of ammonia, besides some other substances, viz., phosphates, carbonates, oxalates, &c. The chief active ingredient is the urate of ammonia, and on that account guano is an excellent manure. But is it *the* best manure? It is curious to observe, how this novelty has been received by many as a peculiarity; and he who sees quantities of urate and carbonate of ammonia daily thrown away in the excrements of men and animals, will readily acknowledge that it is foolish to order guano from Peru at great cost. Until urine or human excrements are collected with more care, and employed as manure, it is unnecessary to send to the Pacific for the excrements of birds,* unless people desire to expose themselves to imposition, for which guano now offers ample opportunity. Agriculture ought to be protected against such impositions, and men of science ought not to expose it to mischief, as has been done with guano. Was it necessary, indeed, to fetch the ammonia from the Pacific? I wish to be rightly understood. I by no means assert that guano is not a useful manure, but only that we are not in need of it.

They who are not better informed, ought not to be blamed because they are deceived by those who know better, and make a shameful use of the ignorance of their contemporaries, for the purpose of obtaining money and reputation.

* Fourcroy and Vauquelin have made an analysis of it, Annales de Chimie, Tome 56, p. 259. Liebig and Wöhler, Annalen der Chemie und Pharmacie, 1842.

Girardin and Bidard, Annales de Chim. et de Phys. Janv. 1844, p. 113. Payen and Boussingault, ibid. Févr. p. 237.

Wherever I could, therefore, I have strongly opposed this guano-fraud, and I do not hesitate to warn against it as being a source of shameful deception. I am equally ready to pronounce the same opinion regarding those multifarious manufactories of artificial manures, of which the present time is so very productive. Every soil, every plant requires its peculiar proportions of inorganic substances; a universal manure is an impossibility. Ammonia is present in the excrements of man and animals, and as regards the organic constituents, those organic substances which are the most widely diffused, have the common property, that in decaying they are decomposed into the five organic acids of the soil, often referred to, and for these there is no need of manufactories. It is by no means honourable to the man of science, to force the most ancient art from its simple and natural condition, and so make it a subject for deception. But there is hope, that the attachment of agriculturists to their usual practice will prevent the evil from making much progress.*

What we have stated regarding the organic food of plants and carbonic acid, water, and ammonia, may thus be presented in a condensed form.

The fleshy plants, several mosses, &c., live upon carbonic acid, water, and ammonia. They contain but little nitrogen.

The leaves decompose the carbonic acid, which they absorb from the air, and whilst expelling oxygen, they produce with the elements of water non-nitrogenous substances.

It is not known, and very improbable, that the leaves absorb ammonia. On the contrary, as ammonia is formed in the soil, and as ammoniacal manures prove beneficial to vegetation by being placed in the soil, it is likely that this substance is only supplied through the roots.

As non-nitrogenous products are formed in the leaves from constituents of the atmosphere, the soil is every year, at the shedding of the leaves, &c., increased by a large quantity of organic substances, which are thus transformed into acid, humic, or crenic bodies.

* A little more experience in practical agriculture would have prevented Mulder from writing this and the preceding paragraph.—*J.*

These substances combine with the ammonia, and thus enter into the plants through the roots in the form of salts.

Although, therefore, I do not deny that some ammonia may be absorbed by the leaves and some carbonic acid by the roots—the latter indeed cannot be denied,—yet the great bulk of the ammonia enters through the roots, and of carbon through the leaves; the water enters through the roots.

The several parts of a bud are consequently in this respect similar to fleshy plants and mosses, that they live chiefly at the expense of the atmosphere. They may be considered as independent plants, fixed in the stem as in a soil. These independent plants (the scions of the buds, that is, the leaves) are the instruments by which the carbonic acid of the air is condensed. They drop and decay, and a large portion of their substance serves to fix the ammonia in the soil, with which it subsequently re-enters the plant through the root.

The organic ammoniacal salts of the soil supply in the first place the nitrogenous substances of plants, viz. the protein with all its derivatives. If they performed no other service than this, they would still be justly considered indispensable.

The scions of the buds (the little plants on the stem, the leaves) extract their nitrogenous substances from the stem, as the latter extracts them from the root, and this again from the soil.

We may present the operations that are going on in the vegetable kingdom by the following cycle: the carbonic acid of the air is condensed and decomposed by the leaves; this carbonic acid along with water is employed by the leaves to form non-nitrogenous bodies; the leaves are shed; they putrefy and form humic and crenic acids; ammonia is produced in the soil from water and the constituents of the air; the ammonia combines with these acids and forms humates and crenates of ammonia; these salts enter into the plant through the root; from these salts nitrogenous substances are formed in the root; these substances are carried up into the leaves and fruits; part of them descends again, along with the products of the decomposition of carbonic acid, to form wood. The leaves are shed and decay, and with this the cycle recommences.

Those principles being acknowledged as true, then it is also true—

1. That plants, as regards the weight of their constituents, live at the expense of the atmosphere.

2. That they cannot live upon the constituents of the atmosphere alone, in the state in which they exist.

3. That the scions of the buds absorb carbonic acid and water, and therefore live in the same manner as the fleshy plants.

4. That the roots serve to prepare the nitrogenous vegetable substances, which are from these transferred into the buds.

5. That every plant, now living in the soil, absolutely requires organic food, and that whenever this law of nature is disregarded in agriculture, the result will show that it is foolishness to attempt the renovation of this ancient art on the faith of unproved theories.

CHAPTER IX.

ON THE TRANSFORMATION OF THE FOOD ABSORBED.

A. On the causes of the transformation of the food absorbed.

The liquid which circulates through plants, is very variable in its composition. We have seen that these differences do not arise from the food which is originally supplied to the plant, but from substances produced in the extremities of the fibrillæ, immediately after it has been absorbed. In different plants these extremities immediately contain products, essentially different from each other, though derived from the same substances taken up from without. These different products are the results of the action exercised by the substances within the plant upon the absorbed food. The very extremities, therefore, of the fibrillæ, are the first and principal places in which the food is elaborated.

It will be necessary to consider, how this change in the extremities of the roots is effected, and how it is subsequently performed in the several parts of the plant.

As regards the first point, it is well known that the fibrillæ of plants increase in length and thickness by the annexation of new cells; that this takes place through the influence of the substances, with which the extremities of the roots are surrounded; that, therefore, these extremities, being themselves capable of increasing in extent, by forming new cells, are very active parts, through which the liquids from the soil cannot pass in the same manner as fluids ascend in

capillary tubes, and far less passively transpire from cell to cell; that, on the contrary, the parts along which these liquids move, exercise an activity, which is communicated to the chemical constituents of the absorbed liquid,—that the former cause a tension which reacts upon the latter; or, rather perhaps, that the former impart motion to the latter.

This truth is a universal one, and without any exception in organised nature, when each molecule is capable of becoming a centre of action, which may far extend itself. It is at the same time one of the greatest importance, in enabling us to form some general idea regarding the transformations which the substances absorbed by plants undergo. Action does not always proceed from every cell through which liquid passes; but it must proceed from all such as either contain substances in a state of transformation, or are themselves composed of these, whilst the influence of these substances must react upon those constituents of the passing liquid which are liable to be thus affected. All this has been sufficiently considered in the first chapter, p. 66.

From this point of view, a wide field opens itself for new investigations. The several systems of the parts of plants, and the various organs they contain, ought to be analysed, and their composition correctly determined; they ought further to be submitted to such a chemical examination, as will explain their influence upon other bodies, especially those that are in contact with them; and the results of these inquiries ought finally to be viewed in connection with the peculiar products, formed by those organs.

Vegetable physiology has not been studied with such a view, and yet there is no other source from which light can be expected to be thrown upon the transformations of substances in this interesting dominion of Nature. Everything that is called, and actually is a cell, does not on this account always contain the same active substances; and some parts of the contents of these cells do not always exercise the same influence upon others, or upon those substances that are present in the adjoining cells. Why, for instance, do

the capsules of the poppy produce a number of different vegetable alkalis, which probably have one common base; but which are certainly found in no other part of the plant except the capsule alone? What causes the production of that principle common to the whole, and of that variety of derivatives from the substances supplied by the plant to the pericarp? What else can have this effect, than a difference of the substances that are originally present in the cells of the pericarp? These substances, formed from the general constituents of the plant, are capable of giving rise to these peculiar products, by the influence of the existing circumstances. The investigation of these substances and circumstances must ere long form the basis of a precise knowledge of the transformations undergone by the food that is supplied to plants and elaborated in their interior.

I have explained, in a preceding chapter, when treating of chemical and organic forces, that every substance, of which the component parts are not united together in a perfect equilibrium—as they very rarely are—must exercise some action as soon as it is brought into contact with certain other bodies. I have further remarked that, especially when substances are either in the nascent state, or in a state of decomposition, this action is capable of being transferred to others, which are then also brought into activity, that is, chemically changed. The latter point has been sufficiently explained at p. 42, where I have treated of fermentation.

Let me apply the principles there mentioned, to the transformation of the food absorbed by plants—to the chemical change which the liquids undergo whilst passing through the cells. This will constitute a true foundation, upon which a more rational vegetable chemistry may be raised. The contents of the cells, especially of those that are young, and the walls of some cellular systems, never consist of chemical substances that are altogether unchangeable. If they are not merely changeable, but in a state of continual alteration, and if they at the same time involve other substances with which they come into contact, in the same condition,—that is, if they contain substances, that are either still in a state

of unstable chemical equilibrium, or in which this equilibrium is more and more disturbed,—then this action must be transferred to other substances, with which they are brought into contact, as is the case with yeast, which is in a continual state of transformation, and communicates that condition to sugar. But as yeast, in a state of transformation, cannot affect *every* substance—being, for instance, inactive towards amygdalin, which can be decomposed by synaptase,—so the substances that are present in the cells of plants, when in a state of transformation, will not be capable of producing a chemical change in *all* the fluids that are passing along; nor will the molecules of the contents of a cell, when in a state of chemical transformation, be able to effect a similar change in *all* the substances with which they come into contact. The action produced must vary with the nature of the substance from which it proceeds; and the action communicated must vary with the degree in which the substances that are to be changed are susceptible of the impression given.

If, therefore, we may ever hope to obtain a knowledge of the way in which the infinite variety of substances in the vegetable kingdom is produced,—and who would give up this hope?—then this knowledge must originate from the investigation of the substances by which the actions in question are produced. These must of necessity be chemically different, to render it possible that one and the same fluid passing through the plant should give rise in one place to a vegetable acid or a fatty substance, in another to starch or sugar, in another again to a vegetable alkali or an ethereal oil.

But, in the second place, this chemical knowledge of the organs, of the organic structure of plants, must be connected with an investigation of the liquids that pass through the plant. When we know the nature of the fluids that pass along the substances which are in a state of decomposition, we shall also understand in what manner the new products have been formed from these substances.

It is plain, that no other than an empirical connexion will

be ever found between the substances produced, and those by which, or from which, they are produced; and that it will never be possible to show when one substance yields certain products, and another substance other products. But this empirical knowledge is the very base of the true science of Nature, and not even a trace of this knowledge can yet be perceived in vegetable chemistry. Such empirical knowledge is the only base of inorganic chemistry, and consequently it must also be that of organic chemistry.

The causes that are at work in plants, are similar to those by which the constituents of the animal organism are continually changed.

Since plants have no system of tubes, through which liquids circulate, such as is found in animals,—although these tubes themselves exercise no influence upon the circulating liquid, —the substances which they contain in a state of solution pass from cell to cell. When these passages are effected, action does not always take place, or at least the action is not always the same. This diversity of actions is to a great extent due to the cells advancing in age, but also to a number of other circumstances, of which the influence upon the transformation of vegetable substances can at present only be stated in general terms. Suffice it here to remark, that the same primary cause which effects the transformation of substances in the animal organism, must necessarily also be active in plants; that is, an action, proceeding from certain general substances, reacting upon others, which is therefore a true chemical action. Further, that the chemical change, which in the animal organism is produced in the liquid secreted from the capillary system by the action of substances in a state of transformation, which have the effect of modifying some of the constituents of this liquid, takes place also in the cells of plants. Finally, that the difference in the products of the same liquid in the animal organism, depending upon the organs into which the above liquid enters, and the difference in the products of different liquids, according to their nature, is in like manner perceptible in plants. The salivary glands and the kidneys both receive arterial blood;

and yet their products are different, because there is a difference between salivary glands and kidneys;—because the same arterial blood, after having entered into these two different organs, is exposed to the influence of different substances in a state of transformation. The same reasoning applies to the production of different substances in plants, when the same juices pass through different cellular systems. If the liver received arterial blood alone, it would secrete substances differing from those which it now secretes, receiving blood likewise from the vena portalis. In the same manner the products will differ in plants, when different liquids pass through the same cellular systems.

In the present state of science, the name of *organs*, which produce new substances, is continually employed. This will require a little consideration.

There can be no doubt that every chemical action, both in organic and inorganic nature, is molecular action;—action proceeding from and reacting upon molecules. Although it may be, that *organs* as such—that is, intertextures of different elementary forms—change and modify the manner in which the substances are moved, and the position in which they remain together,—yet *organs* produce no chemical changes, but merely elicit them. *Organs* cannot produce chemical action, because chemical action is nothing else than the manifestation of a certain condition of molecules, and this condition they cannot receive from *organs*. Whenever, therefore, I use the word *organ*, I wish to have it understood in this sense.

The idea, therefore, of the production of new chemical bodies, either with or without any definite form, is founded on the idea of molecular action.

On looking at the substances that are present in the plants of the more simple or lower order, and in the higher plants, we perceive that there is a considerable difference between them. In like manner we perceive differences between the peculiar substances of animals of different classes; yet these are less important than those in plants. In plants, and also in animals, these differences arise from differences in the organs: for thus the same food, absorbed by plants, is placed in

totally different circumstances, in consequence of which they assume an entirely different natural position, and react upon each other in a totally different manner.

There is a considerable difference between the substances that exist in plants and in animals. Gelatine is not found in plants, cellulose does not exist in animals;* plants contain no chondrin, animals no starch nor gum; plants are devoid of haematin, animals contain no vegetable alkalis. In the latter we find, further, but a small number of peculiar substances that do not belong to the class of *secretions*, and are, therefore, in the more restricted sense, no constituents of the body, whilst on the other hand, plants contain a great number of other substances besides, viz., volatile oils, resins, gums, acids, neutral nitrogenous substances, &c., in a word, an innumerable variety, part of which, however, must also be considered as secretions.

When we look at *substances produced*, we find those of animals are simple in their composition, while those of plants are the reverse: but when we look at the organisation itself, we find that this is very simple in plants, and the reverse in animals. We find an inverted proportion between organisation and chemical constituents in the two kingdoms. The reason of this is very obvious. When one and the same liquid circulates through an organic whole impelled by a heart, propelled through tubes and arteries towards *every* part of the body, and returning through other tubes (veins) towards the same heart, the number of substances of a different nature can be but small. When, on the contrary, every part has almost an individual existence, and the connexion between the several parts is certainly not direct, but indirect, and when there is no *circulation* of one and the same liquid through the whole, any small difference between the organs must give rise to a great difference in the products. This explains how the complicated nature of the organisation of animals is the very cause of the simplicity of its products.

* Schmidt (Zur vergleichenden Physiologie, 1845, p. 36) found cellulose in Ascidia mamillaris and Frustulia salina.

This difference between the organisation of plants and animals causes so great a difference in their several functions, that it is difficult to compare them together. In plants we find no trace of a system of circulation and respiration, of stomach and intestines, of livers and kidneys, of brain and nerves. All this, especially the absence of the two latter parts, draws a clear line of distinction between the functions of animals and plants. Although they exercise several vegetable functions in common, both absorbing substances and elaborating them, and even produce some substances of the same kind, yet as regards all other functions plants and animals are entirely different.

Of late it has often been pronounced a law of nature, that plants prepare, and animals consume, organic substances. A mere glance at the chapter in which I have treated of the constituents of the structure, will rebut this assumption, and consequently it falls to the ground. This law is not one of the old, but of the *new laws* of Nature, in which the present time is very rich.

The organic kingdom has this principal characteristic: that the substances which it contains are in a state of continual exchange. If we knew but one substance in plants which is always in a state of transformation, there would be at least one point to guide us in the explanation of the change of materials. The question here is not, if the transformation of that one substance would enable us to trace the production of every other; but we would have gained much, if we could with certainty point out one primary cause. In meteorology such a cause can be certainly referred to; it is an important recent discovery, that the heat of the sun is the only cause of the change of the weather; and yet no body will undertake to trace *every* change to the unquestionable principle just mentioned

It would be an important acquisition if we were acquainted with a general substance in the organic kingdom which must naturally be in a state of transformation; such a substance could then be regarded as a focus of action and every subsequent change produced by it, might then justly be called

a new centre of action. In other words, if science were able to point out in the vegetable kingdom a substance, which is in a continual state of transformation, then that idea of vital action, which I feel myself warranted in entertaining (1st chapter), would receive a powerful support.

There are strong grounds for assuming that the same substance, which is in the animal organism the first source of chemical action, performs the same part in plants;—that is, the complex group which we call protein.

It is erroneously stated that this substance is elaborated by plants, and consumed by animals; for although it is true that it is formed by plants, and probably not by animals, yet the plants themselves consume a considerable proportion of the protein which they form.

The nitrogenous substance found by Payen in the extremities of the roots of plants (p. 248), is undoubtedly some protein compound, although it is not known which. But this is of no importance to the present purpose, because *all* protein compounds possess the property, that when the substances between which a change of materials takes place occur in plants, they are decomposed and converted into new products. Most likely these very fibrillæ are the only place where this protein is formed. It is at least certain, that it is formed there, because it is found there. That this protein supplies the nitrogen to the chlorophyle, the vegetable alkalis, and the other nitrogenous bodies, is equally probable, as that in animals it supplies the nitrogen to gelatine and chondrin. But further, if protein is really the source of every action in plants, its decomposition must necessarily make it decrease in every part where its nitrogen produces ammoniacal salts, or where ammonia is expelled in the state of gas. (See *Exhalation of Plants.*)

Payen* discovered it in almost every part of a plant, although in very different quantities. When treating of the structure of plants (7th Chapter), we have found this substance of frequent occurrence, and we know besides, that it forms very frequently part of the contents of the cells. This

* Mémoires s. r les Développemens des Végétaux, p. 17.

generality of its presence indicates a generality of service, and subtracting what is left in the seeds and other parts of the plant, the remainder can hardly perform any other service than to become the source of a change of materials.

It deserves special notice, that protein is formed at the extremities of the fibrillæ, and is in other places again partly consumed and decomposed. These fibrillæ are in this respect quite opposed to the other cells of the plant, and they therefore require a peculiar consideration.

Are these fibrillæ wholly peculiar organs? Certainly not; they are only groups of cells, of which the form presents nothing remarkable. But they are placed in entirely peculiar circumstances, and these make them different from all the other cells of the plant. The contents of the cells of the fibrils, whilst in a state of action, that is, of transformation, are mixed with a very complex group of organic substances from the soil, which are also in a state of transformation, and this intermixture must necessarily produce peculiar substances which cannot be formed in any other part of the plant, because these circumstances are not repeated in any other part. Now, as protein is found at the extremities of the fibrillæ, and could not have been brought there from another place, *it must be directly formed from the organic ammoniacal salts of the soil.*

It was for this reason that I have called the organic substances of the soil indispensable (p. 651).

From these extremities, the protein is carried throughout the plant, but at the same time it is here and there altered, lessened in amount, or converted into new products. Part of it is carried away unaltered, in a state of solution in water, and conveyed towards the young branches, from which it reaches the fruits and leaves, where it is partly deposited, and partly decomposed, and converted into other substances. Payen found nitrogenous substances both in the juice of cucumbers, and in the liquid obtained from a branch of the elder tree, by washing it with water. The sap of an oak branch, of a mulberry, a fig tree, a linden tree, a poplar, and many others, all yielded ammonia by destructive distillation

It is to be regretted that Payen has not examined what kind of nitrogenous substance exists there, for it is plain that it will not always be the same substance. His experiments have not settled this point. As, however, every part of a plant without exception contains protein, we are entitled to trace part of the ammonia which Payen obtained to this source. I myself found it *always* present.

It is well-known that one plant contains a larger quantity of this nitrogenous group than another. The coniferæ contain but little of it, while in the gramineæ a large quantity is present. Among the plants that are used as food, almost none contain so much albumen as the various kinds of cabbage; and they are, therefore, like the corn plants, excellent for food. When the juice of savoy cabbage is heated, a very considerable coagulum of albumen is produced. The fresh sap of every plant yields more or less of this substance. The amount of nitrogenous substances contained in plants indicates the necessity of a proportionate quantity of nitrogen being present in the soil. Plants, therefore, that are rich in nitrogen, require manures containing a large proportion of organic ammoniacal salts.

Although it is by no means certain as yet that an albuminous substance is the only one that is in a state of transformation, and should therefore be considered as the primary source of action in plants, it is beyond doubt that this substance acts a principal part in this transformation. This is not at all at variance with the fact that albumen is formed in plants; and it may very well be formed and decomposed in the same individual. If these two operations were performed on the same spot, in the same series of cells, then it would certainly appear contradictory. But whilst it is formed in the extremities of the fibrillæ, it may very well be that it is decomposed in some other place.

In short, we may adopt the principle that plants contain a substance generally diffused, which is formed at the extremities of the fibrillæ, and being partially decomposed in the plant, thus becomes the source of the change of materials which is there performed.

But the phenomena of the Vegetable Kingdom cannot be fully explained without the assistance of a second substance, viz., one which is the cause of those frequent de-oxidations by which phosphates and sulphates are decomposed, metallic salts reduced, and carbonic acid made to furnish carbon. It is possible that the primary causes of these de-oxidations may be several in number, but it is plain that one would be sufficient. If we knew one single substance which could predispose the organic elements to *lose* oxygen, as we know that by elevation of temperature they are enabled to *absorb* it, we should indeed have advanced a great step. But such a substance can as yet be fixed on only by supposition, and I think we might in this respect pay some attention to Scheele's soapy matter (saponine).* This substance is not only very generally diffused, but also very easily changeable, and prone to absorb oxygen, and it may, therefore, safely be considered as one of the substances in the Vegetable Kingdom which are capable of inducing these frequent de-oxidations.

But whether or not the soapy matter of Scheele be such a substance, there must be one of this kind, which, like protein, is formed in the fibrils, and is from thence diffused throughout the plant; one which communicates its own condition to every substance with which it comes in contact, and therefore predisposes everything to part with oxygen, and the oxygen itself to be separated.

It is evident that such a substance cannot be produced from the food that has entered through the leaves, nor from the carbonic acid, which is so rich in oxygen.

It can only be produced from the organic food of the soil, and being formed in the root, and from thence carried upwards, it will spread its influence through the whole plant.

It is an important question to solve what that substance can be. But whatever name it may bear, we are already perfectly acquainted with its chief property, viz., to induce the separation of the oxygen,—to deprive the carbon, hydrogen,

* I take this substance, however, at present, as a single organic group, although it may contain several combined

and nitrogen, of the power either of uniting with oxygen or of remaining combined with it.

But if *protein* is formed in plants and partially employed to elicit a change of materials, and if *soapy matter* is formed in plants, and partially employed to produce a tendency to de-oxidation, what are the means through which this protein and soapy matter are at first prepared? I shall endeavour to offer some explanation on the first point.

If the protein in the fibrils is once in a state of production, and if it is produced from the ulmates, humates, geates, apocrenates, and crenates of ammonia in the soil, then we can conceive the continuation of that production *in* and *through* itself, as we can form an idea regarding the continuation of every action in Nature *in* and *through* itself. I have again recourse to the example of yeast, because this substance is, as it were, continually in a state between death and life. As soon as one single cell of yeast has been produced in a fermenting liquid, the formation of more, of numbers of cells commences, and soon innumerable quantities appear. Is the one produced by the other? We have observed (p. 76) that organic beings do *not* produce. The circumstances through which the first cell of yeast was formed are supported, and continue *through* and *in* this production; the formation of a second cell is therefore a direct consequence of the continuation of these circumstances, and this goes on until the material has produced the last cell of yeast.

If one cell of yeast, whilst in the nascent state, has the effect that the circumstances, favourable to this production, continue to act in two or more directions, then the substances that are placed in these several directions will at the same time be affected, and consequently one globule of yeast in a short period be followed by two and more others. Each of these new cells again direct the existing circumstances in the same way, and thus a very rapid increase of the cells will naturally be effected.

Now if we apply the same reasoning to the cells of the fibrils, then we obtain at least some idea of the production of protein within them, and of the continuation of this action. There

can be no doubt that this production is contemporaneous with that of the cells of the fibrils themselves, and that the organic salts of the soil, mixed with inorganic substances, are the materials of production both for the protein and the enveloping cells;—in the same manner as the cells of yeast find these materials in the saccharine fluids, mixed with albumen and dextrin.

We know nothing whatever regarding the manner in which the carbonic acid, when taken up by plants, is included in the circle of transformation and converted into food. It was long known, and generally acknowledged as a fact, that plants have the power of decomposing carbonic acid, and that therefore this must be the material from which the substances, contained in plants, are produced. Although this had already been remarked by Ingenhousz, yet Liebig was the first who brought it under the notice of physiologists, so as to draw general attention to it. But what has thus been brought to light, is confined to the general notion, that the organic constituents of the soil are insufficient for the growth of plants; that the latter must derive part of their substances from the atmosphere, and that from this source they can obtain nothing else than water, carbonic acid, oxygen (and nitrogen). I consider it, however, as certain, that Liebig, by placing these known facts in a clear light, has rendered an important service to science.

I have said that it is not known in what manner the conversion of carbonic acid within plants is effected, what becomes of it, and by what means it is made to undergo that change. We may, however, present it under a general point of view. In the present state of science, we may safely conceive, that some vegetable substances act upon carbonic acid in a manner exactly the opposite of that in which porous inorganic bodies, such as pumice-stone, and especially spungy platinum, act at a somewhat elevated temperature upon tartaric acid, citric acid, oil, butter, and other substances. (Reiset and Millon in Ann. de Chim. et de Phys. Juillet, 1843, p. 180.) All these are decomposed into carbonic acid and water, in consequence of, as we call it at present, some chemical

impulse or impression which the substances receive from platinum, or pumice-stone, heated to a certain temperature;—in other words, by catalysis, as we usually call it (see p. 32). In olive oil this change is even effected at 276° F., in butter at 294° F.

Now, there are certain vegetable substances which appear to act in a directly contrary way. When water, impregnated with carbonic acid, is absorbed by the roots of plants, the leaves give out oxygen instead of carbonic acid. The carbonic acid that is absorbed and retained by the leaves, is under similar influences transformed into vegetable substances. This fact admits of no doubt, but we have not yet advanced any further, and, as science can afford us no satisfactory explanation on this point, unless it enters into particulars,—which it has not yet done,—we are bound to acknowledge, that we are completely ignorant on this subject.

I cannot, however, conceal my surprise, that we should be so much satisfied with the amount of knowledge we possess of other phenomena that are equally obscure, and that on the other hand so much should be required from the science of life. Fermentation is considered duly explained, by stating that the yeast decomposes the sugar, converting it into carbonic acid and alcohol. But it may be asked, do we understand this decomposition? We must confess that we do not; but we acknowledge it as a fact, because we see it.

But if we saw not a *decomposition*, but alcohol and carbonic acid *combining* together into sugar, through the influence of a third substance, should we understand this in a less degree? Certainly not, for we cannot understand less than *nothing*.

But if we do extend our desire to a thorough *understanding* of this subject, because there is no action in Nature into which we can penetrate far enough to obtain a pure and full *conception*,—and if we rest satisfied with representing the *idea* itself under a certain form, then this idea will not be altered in value, whether we add carbonic acid to alcohol to obtain the composition of sugar, or subtract carbonic acid from sugar, for instance:—

From sugar,.....	C^{12}	H^{12}	O^{12}	
Take 4 of carbonic acid,	C^4		O^8	C^4
And we have alcohol,...	C^8	H^{12}	O^4	C^4
Or to alcohol.	C^8	H^{12}	O^4	
Add 4 of carbonic acid,	C^4		O^8	
And we have sugar,	C^{12}	H^{12}	O^{12}	

The duty, therefore, which vegetable chemistry has yet to perform with regard to the carbonic acid, is to explain into what class of substances this carbonic acid is transformed, or with what groups of substances in plants it is united, connecting them into more complex bodies.

It appears from the old experiments of Ingenhousz, and is confirmed by every one that has since been made—that carbonic acid is not decomposed in the dark, but only through the influence of the light of the sun; that the leaves and other green parts do not emit oxygen in the dark, but only in the sun.

This leads to two important conclusions:—1st, That only those part of plants, which are either thin or penetrable by light, afford an opportunity for the decomposition of carbonic acid, and that this must therefore take place chiefly in the leaves. 2d, That the carbonic acid, which enters into the root along with the rain-water, being beyond the influence of light whilst in the interior of the plant, cannot be then decomposed; but that, with the exception of a part which reaches the surface of the stem, and is thus exposed to the light, the rest must ascend into the leaves, to be there decomposed by the influence of light.

It is very possible, however, that the de-oxidising substance, which causes the decomposition of carbonic acid in the leaves under the influence of light, gives rise to other products of de-oxidation of organic groups in the interior of the plant, and without the co-operation of light, converting substances rich in oxygen into such as contain but little of this element.

We have, therefore, apparent reason for the following conclusions:—

a. We know no substance in plants which contains so much oxygen as carbonic acid; whilst there exist on the contrary in plants many substances free from oxygen. In plants, therefore, there exists a tendency to de-oxidation.

b. The carbonic acid absorbed can produce by itself no new compound, but requires for this purpose the aid of other substances.

c. It is unlikely that water alone would be sufficient for this.

d. A small quantity of the organic constituents of the soil is indispensable to the growth of plants. It is possible that these substances, which without the plants have always a tendency to oxidation, act first upon the carbonic acid, depriving it of oxygen.

e. As heating promotes oxidation, so the growth of plants promotes de-oxidation. As one substance, when in a state of oxidation, excites the same phenomenon in another substance, de-oxidation acts in a similar manner in plants.

f. If we therefore knew but one general substance in plants, dissolved in the sap of the cells, and being naturally in a state of de-oxidation, in the same way as sulphur or potassium is always in a state of oxidation, then we could explain the general tendency of plants to de-oxidation. Such a substance, however, is as yet unknown.

g. But from whatever substance this de-oxidising action may proceed, the phenomena themselves are clearly apparent, from the reduction of metallic salts to the metallic state, or to lower stages of oxidation (p. 625), from the production of fats and ethereal oils, and from the emission of oxygen itself through the green parts of plants.

h. We do not look for the source of this action in *organs* as such, but in *substances* which the plants contain; for all the products of plants, whether of a definite form or not, are the results of the mutual actions of matter.

The nature and composition of many general substances which are common to all or the greater number of plants, leads to the natural conclusion, that in the majority of plants the food must in most cases undergo the same change.

because otherwise it could not produce these general substances. Cellulose, albumen, mucilage, starch, chlorophyle, incrusting matter, and several others, are but seldom absent in plants. Nature, although multifarious in its modifications, is simple in its principles; for a small number of principal substances constitutes the entire animal and vegetable kingdom. (See Chapter VII.) But this general diffusion of the same substances which are the fundamental materials from which the bulk of the whole is built up, is the very reason of the difficulties attending the investigation of the great variety of special products. The bulk both of an oak and a fir tree is incrusted cellulose; and yet, although they may grow near each other, the former is full of tannic acid, and the latter of volatile oil and a resin, the product of its oxidation. The same food, therefore, produces the same, and also different substances, which can arise from nothing else than from a difference in the composition of the masses, which are apparently similar, or rather, which must be explained by a difference in the composition of quantities, however small, of peculiar substances in the seed of the plants. This difference, however similar the products may be, must, from the very beginning of the development, give rise to a certain diversity in form and products, which, once existing, is maintained throughout the life of the plant, and passes to all the succeeding generations, because the same plants produce the same seeds with their invariable peculiar substances. The *gross* result of chemical analyses, viz., that different kinds of wood approach each other in composition, or that different vegetable tissues, after being treated with various solvents, always yield the same cellulose—these results tell us nothing regarding the true composition of that active substance which causes and influences the transformation of the food. Such chemical investigations cannot serve for the explanation of any function; and hence we may see the still defective condition of natural science.

When considering the changes that take place in the chemical substances of which plants and animals are composed, we pay too little attention to what must ensue, when they

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condition, flows from the capillary system as nutritive liquid. There it meets with soft tissues, which also are in a humid state, are at a temperature of 100° F., and consequently also in a state of decomposition; for when meat is exposed to the air at 100° F., it is decomposed in a few days. The substance of the muscles, and all other parts, are likewise decomposed *within* the body of the animal, although the products may be different from those formed without the body. In this manner there is a mutual contact between blood and tissues, both in a state of decomposition, and this produces a reciprocal reaction, which terminates in a new change of both.

It is much to be regretted, that so-called dead and living nature have for so many years been placed in opposition to each other. Notwithstanding the manifold differences in the products of both, the changes occurring within and without the organic body are in many respects similar. However great these differences may be, the decomposition of organic substances both within and without an organic body arises from one and the same primary cause, namely, from the forces that are inherent in the elements of which these substances are composed.

The only question is, in what respect do the circumstances differ in which the same substances are placed? When organic substances are left completely at rest, at a certain temperature, and in a certain degree of humidity, they give rise to other substances, which are called at one time products of fermentation, at another products of decay (eremacausis), or of putrefaction. When moving in a system of closed tubes, and in contact with other substances, the resulting products are of a different character, different, not because the decomposition itself is of a different nature, but because it takes place under different *circumstances*. For instance, organic substances and sulphates, which are present both in sea-water and in the intestines of mammalia, give rise in both cases to the same gaseous products, viz., sulphuretted hydrogen, carbonic acid, and carbonic oxide; the oxygen of the [illegible] disappears, but the nitrogen is left

The blood which circulates through the animal body, is in entirely different circumstances, and the mode of decomposition is therefore different. Yet decomposition takes place, and arises from the same causes by which the gases mentioned above are produced in stagnant water, or in the intestines of mammalia.

Heat has an unlimited influence in changing the chemical forces of the elements, and consequently in modifying the composition of the compounds. The truth of this is apparent from the effects of destructive distillation; for in this operation we are enabled to convert the same compound into entirely different products, merely by applying different temperatures.

A precisely analogous case is exhibited in the animal body. The liver and the alimentary canal are always exposed to the same temperature, and therefore the change in the elements of the blood, within these organs, must be influenced by the temperature in a manner different from what takes place in the skin, where the temperature is variable. This difference between these two distinct parts reacts upon the entire organism; for all parts are brought into mutual relation by the system of blood vessels which pervades the whole.

The different amount of heat, peculiar to different classes of animals, has a similar influence upon their functions. This heat is partly an effect of the chemical change of materials, though on the other hand it gives to this change the specific directions in which it is performed. For these reasons, therefore,—leaving others *at present* out of sight,—the products of the decomposition of the blood in reptiles differ from those of the blood in birds and mammalia, because their bodies possess a different temperature.

In the vegetable kingdom there is much less connexion between the several parts of an individual, because there is no circulation through a central organ. Yet we here recognise the same primary causes of action as in animals, namely, a continual change of materials, provided the elements of which the compounds consist are predisposed to this change by heat. A vegetable sap, which ferments without the plant,

cannot be inactive within it. In the latter case its constituents are also changed, but in a manner different from what takes place in fermentation, because there are differences both in the exchanging substances and in the circumstances attending them. By a low temperature both fermentation and vegetable functions are paralysed; by the heat of summer both are excited.

In animals there exists a circulation, put into motion by means of the heat, and this causes similarity in their products, and simplicity in their effects; in plants, on the contrary, no such system for the circulation of fluids exists, and this is the cause of that unlimited variety of organic products which we find in them. Every where portions of the general nutritive fluid are withdrawn from the influence of the remainder, and these portions, being enclosed in separate cavities, subject to peculiar influences, may undergo peculiar changes, of which the manifestation is characterised by entirely peculiar products.

Besides the intermixture of heterogeneous substances in the various cells, of which the mutual contact must give rise to an exchange of constituents; and besides the summer's heat, which may be compared to the temperature of digestion,- there exists another important source of chemical action among the substances which are enclosed in the cells of plants in a state of solution, viz., the light which shines upon plants. From inorganic chemistry we can quote instances of elementary bodies being united solely by the action of light; for chlorine and hydrogen are thus combined into hydrochloric acid. Therefore, what we see take place in the leaves, viz., that under the influence of light, they emit oxygen in return for the carbonic acid and water absorbed, and produce new substances, such as wax,—is an action analogous to that which we see in the mutual action of chlorine and hydrogen. Light, therefore, is a powerful exciter of chemical action in plants, a source of multifarious changes of material: a cause of important functions of the vegetable kingdom.

We have already remarked, that light exercises its influence

only on the surface, or in the transparent parts of plants. But as soon as by the influence of light, peculiar substances have been formed at certain places, they are by an endosmotic exchange readily transferred to other parts of the plant, where they induce a new change of materials.

There exists in plants a peculiar source of this change, which must without doubt be ascribed to a concurrence of causes, individually of little power, such as small differences of temperature, light, evaporation, or endosmotic exchange; but which, whatever its origin may be, appears as an important cause of transformation,—I mean, the so-called *motion* of Brown. It is exceedingly interesting to observe the continual motions of minute molecules in the limpid contents of a cell; to see them attracting each other, the one revolving round the other, and sometimes circulating along the cell-wall in a regular direction. It is a phenomenon highly attractive, which the observer can scarcely behold long enough.

This uninterrupted motion, which we must naturally suppose to be performed by *every* particle of the contents, because those that are *visible* are in motion, must have a most powerful influence upon the change of materials. This motion overcomes the inertia of the molecules, and establishes a mutual contact between these of a most dissimilar nature.

But though this motion is one *cause* of the change of materials, it may, whilst this change takes place in the contents of the cells, be partly an *effect* of it. This motion is not, however, an effect of the change of materials alone, because it is also performed by neutral substances, provided they are in a state of very fine division.

It requires a mere glance at the phenomena that take place in the vegetable kingdom, to induce us to divide its products at once into two classes, viz., those that are in a state of transformation, and those that have been transformed, and undergo no further change. I consider this an important distinction. Besides the so-called secretions and excretions there are many —and these constitute the main bulk of the solid parts of a plant—which, being once formed, undergo no further change.

Of the latter class is the entire woody tissue, which successively extends itself, and of which the walls become incrusted, but without its undergoing any further chemical change.

This, therefore, constitutes a real difference between plants and animals. In the latter the several parts of the structure are throughout their life more or less renewed, a renovation to which most of the parts of the vegetable structure are not subject. It is an erroneous expression, therefore, to call fully formed wood a living substance, for no renovation of its substance takes place: it persists in its acquired state, and the reason why it exhibits no phenomena of decay or putrefaction is, that it remains beyond the reach of those influences by which such changes could be produced. The cuticle, the cells of the epidermis of full grown plants, and even all cells consisting of pure cellulose and duly developed, may likewise be called lifeless, because the change of materials has here entirely ceased. Their existence is similar to that of the hair and nails of animals. The elementary parts of plants of this class are very numerous, and likewise, therefore, the substances of plants that ought not to be called living although they transmit fluids and are from time to time covered with new layers.

The substances in plants which are in a state of transformation are so in very different degrees. They are of two kinds. Those from which the primary cause of action proceeds, and by which it is sustained—these substances must be present in every seed, nay in every living organ of plants—and those which are brought into motion by the former,—these constituting the food and all that is produced from it,—until they have reached a certain point where the action ceases and they have come to rest. If this exchange went on without interruption, and if certain groups were not withdrawn from the powerful deoxidating action, the whole vegetable kingdom would be resolved into ethereal oils without oxygen.

The transformation, therefore, in which the elementary parts of plants are engaged, is an effect of the presence of substances which are brought into chemical change through heat and light and involve others in a similar change. In

like manner the state of rest of those which are not further transformed, arises,—1° From the absence of those energetic groups of which the constituents are always changing. 2° From the discontinuance of the access of water, which is necessary to keep the molecules in motion; or, 3° From a certain state of equilibrium of the elements of such groups, which is too stable to be affected by disturbing influences.

The following points are to be attended to in the investigation of the change effected in the food, after it has been taken up by the plant. 1° The food itself. 2° The manner in which it penetrates through the exterior of the plant. 3° The organs through which it moves. 4° The way in which this motion takes place. 5° The solid substances which are separated from it, and constitute the materials of which the tissue of the plant is built up. 6° The liquid contents of cells and vessels. 7° The solid, liquid, and gaseous substances which are excreted by the plant.

The first two points have been considered in the former chapter. The third, fourth, fifth, and sixth now claim our attention.

G. Of the Organs through which the Food moves in the Plant.

The organs in which all that belongs to the food of plants must be contained, and through which it can be conveyed from one place to another, are cells and vessels. These are the organs, in which the change of the food must take place.

1° *Of the Cells.*

With reference to the change of the substances that are taken up from without, we divide the cells into thin-walled, consisting of pure cellulose, and thick-walled, which contain other substances besides. Thin-walled cells are thin, membranaceous bags, by which the sap, with all that it contains, is divided into innumerable small portions. After being formed, they do not exercise any, or only a very feeble chemical influence upon their contents. They may almost be con-

sidered as inactive receptacles. They consist of cellulose, combined with a small quantity of inorganic bases, and contain not a trace of those nitrogenous substances which are capable of bringing other substances into activity. Their chief service, therefore, is to act as little reservoirs, minutely subdividing the fluids, so as to prevent them remaining in one continuous mass. If a plant were one single bladder or cell, filled with liquid, only one kind of change of materials could be produced. The diversity of this change, by minute differences in external influence, will increase with the augmentation of the number of the cells, which were originally filled with the same liquid.

Let us imagine a plant, consisting of nothing but cells, which are for a moment everywhere filled with the same liquid. Whilst moisture is evaporating at the extremities of the plant, leaving solid matter behind, these spots must be the starting points, where a general diversity in the liquid of the cells is first produced, and of which the natural effect must be, that the substances produced will vary with the height to which they have ascended. A thin, watery liquid is continually supplied from beneath, whilst water is evaporated at the top. The saps that are most concentrated, all undergo the greatest change, and their products will present the greatest variety. These cells, however, are membranaceous bags, between which there is an endosmotic interchange. The greater, therefore, the diversity produced by simple evaporation, the greater will be the difference produced by the endosmotic interchange of the substances contained in the cells.

Cellular plants, therefore, contain those substances which can be produced from their contents by the mutual action of the constituents. They are to be considered as a series of little troughs, filled with various kinds of liquid; little troughs through which these liquids can pass and mix together, thus not only sustaining, but even increasing their diversity. All the new substances formed in such a plant, are the products of the mutual action of the constituents of the cellular sap

There are, however, two sources of interchange, which must be taken into account. The seeds from which the first cells of such a plant are developed, impart to it, not only a series of cells, but at the same time active cellular contents. In other words, the new plant, which grows from the seed, on receiving the contents of the cells of the latter, is supplied with substances that are in a continual state of transformation, which they communicate to everything with which they come in contact; in short, with substances that excite activity.* This activity is awakened in each seed in a peculiar manner, because the same substance whilst in a state of transformation, when affected by small differences, must produce different results. The seed produces the plant, but the plant also produces the seed, and thus it is that these differences are maintained in every case.

Difference of place soon causes a difference in the formation of new substances, which is assisted by external influences. Although the activity is awakened by one single substance, yet the products are different, because the same substance soon begins to act upon greatly diversified substances. In like manner the same fire affects different substances in a very different manner, and the same sulphuric acid, when acting upon different substances, produces widely different results.

In a few cellular plants there exists still another cause by which new substances are formed in the contents of the cells; a cause, however, which itself depends on the transformation of part of the soluble albumen. This cause is the formation of new cells. These young cells have their origin in the dextrin of the contents of the existing cells, through the influence of soluble vegetable albumen. This is proved by the formation of ferment, and although we do not know why dextrin is converted into little vesicles by the influence of soluble albumen, yet the fact is certain, and consequently we acknowledge it as such.

* All seeds contain protein; some, however, such as that of Phytelephas macrocarpa, in so small a proportion, as to show that even a trace of this substance is sufficient to constitute a source of manifold chemical changes.

Now, when in a developing plant there is a continual transformation of dextrin into cellulose—the means being soluble albumen, which is itself in a state of change—then this formation of cellulose from dextrin is in its turn a source of renewed changes, and disturbances of the chemical equilibrium, which in their turn react upon the contents of the cells. Besides, every new cell causes the change of a large quantity of liquid matter into a solid state; thus the solution has lost part of the substances composing it and has become in this manner a new source of disturbance of the equilibrium between the constituents of the contents of the cells, that is, the cellular sap.

This may suffice with regard to the *thin*-walled cells, as regards the change of the absorbed food within the plants. The last mentioned effect is in a much higher degree exhibited by the *thick*-walled cells; for as the quantity of solid substances, secreted from the cellular sap to form the constituents of the cells themselves, increases, the continual change of that sap becomes greater, and thus additional chemical actions are called forth.

We perceive from what has here been stated, that in every peculiar cellular system in the several plants, a peculiar change of materials may, and even must take place, that in every cellular group which by any cause is isolated from the remainder, a peculiar action in the contents of the cells must take place, even although these contents are the same throughout, and that these peculiar actions may and must issue in peculiar products. This is actually in accordance with experience. In the stem of dicotyledons, where the several organs adjoin each other, the different parts are irregularly developed, according to their position. This difference in development, which may in its turn be an effect of a difference in the ascent of the sap, must necessarily be attended by differences in the contents of the cells and thus also by a diversity among the new products.

But this appears still more distinctly in the different organs of plants. The stamens and pistils cannot possibly produce the same substance as the petals, even although they

received the same cellular contents, because the latter are then placed in totally different circumstances. On whatever organ we fix our attention, we everywhere meet with such a diversity of circumstances; and though all the organs should contain one uniform mixture of the same organic and transformable substances, it is clear that a diversity in the production of new substances must be closely and intimately connected with, nay, perhaps, entirely dependant upon, the different circumstances in which the same liquid is placed, and which must in its turn, to a certain extent, give rise to a diversity of organisation.

I say to a certain extent; for who will venture at present to speak more positively about those constant forms, both internal and external, which in the Vegetable Kingdom excite our admiration? It is self-evident that these forms are dependent upon matter, upon the general properties and forces with which matter has once for all been endowed by the Creator; but we are not yet able to comprehend in what manner this is effected.

We see clearly and distinctly, that when similar substances are placed in dissimilar circumstances, they form different combinations, and we consider this simple rule an index to guide us in the consideration of the products of the Vegetable Kingdom.

It is evident, from what has been stated, that the chemical productions of plants, whether they belong to the *contents*, or to the *cells*, or *vessels* themselves, are not to be considered as the result of a peculiar action of these parts as mere instruments —a view which is based upon an indistinct idea of what takes place. In most cases the difference in the contents of a system of cells is the only indication of the diversity of the organs, and this points distinctly at the causes by which the difference in the contents has been produced. These differences can only originate in the cellular contents, in a mutual interchange of constituents, without the slightest influence of any part of the cell wall. In this respect the *organs*, in the ordinary meaning of the word, are completely the same, however different their contents may be.

It is only when there is a difference either in the *composition* of the constituents of the walls, or in the *form* of the cells, or in their *size*, *position*, or mutual *connexion*, that the *organs* may be called different. These are the circumstances, either individually or collectively, which are the causes of the *different* changes of the constituents of the contents of the cells. They effect a shorter or longer stay of the substances that are dissolved in the watery liquid, make them remain in each other's neighbourhood for a shorter or longer period, and thus modify their mutual chemical reactions. In one place they cause the water of the saps more quickly to evaporate, which makes the remaining liquid more concentrated, and increases the mutual chemical reactions of the substances which it holds in solution. In other places they induce either the access or the removal of one or more substances, and thus afford additional opportunities for chemical changes. In a word, the so-called organs of secretion in plants are cellular groups, of which the function simply depends upon, as we usually express it, the *circumstances* in which they, and with them the contents of the cells, are placed.

This view leads to the conclusion, that the terms *elaboration*, *more highly-organized*, &c., may henceforth be dispensed with; for these terms are either based upon an incorrect idea or are altogether unintelligible. We must, on the contrary, look for the causes of the action, mutually exercised by different groups of organic substances, in order to explain the formation of the various peculiar vegetable products. Neither do I distinctly understand the difference between *crude* and *assimilated* substances, and I even consider such a distinction injurious, because the term *assimilated* leads to an erroneous conception. In my opinion all these words do injury to science, because they are mere sounds.

In each cellular system, therefore, a peculiar transformation takes place, dependent upon the form, the contents, or the wall of the cells. The form also regulates the entrance, emission, and the interchange of the contents. The various forms of cells enumerated in a previous chapter, cannot, therefore enclose the same substances, nor have the same

wall, which is a product of these substances. This I had in view at p. 349, where I endeavoured to take a conjoined view of their form, composition, and function.

Decandolle, many years ago, made known the remarkable fact, that plants which have a similar external form, are also similar in constituents. The external form of plants is nothing else than a product of the form of the component parts, which cannot constitute a similar product, unless they themselves are similar to each other, and cannot produce different forms, unless they themselves are different.

The *parenchymatic* cells, which are only bordered all round, and the contents of which have mutual communications, are the most frequent in herbaceous plants. Whole families of plants of the lowest order consist of these cells. Their contents differ from each other in an almost unlimited degree;—much more than can be accounted for by their difference in form. While, however, two groups of these cells in the same plant differ from each other in form, the cells of the same group seem to agree in colour and shape much more with each other than with the cells of other groups. In confirmation of this I need merely to refer to every part of a plant containing coloured substances. It is to be regretted that the microscopical part of chemistry, by which alone this subject can be to some extent cleared up, has not even kindled a spark of light as yet for this purpose, and that we must derive our distinctions from diversity of *colour*.

When the parenchymatic cells have the same form but different contents—a case which obtains in an innumerable multitude of plants,—then this difference may be explained from a very small original difference in the contents of the cells of the seeds, from which these plants have been produced.

It holds good in all Nature, nay in every thing, that a small, almost imperceptible, difference, in the primary cause, produces effects of an unlimited diversity, when the action of this cause is transmitted under small deviations. But it is at present quite impossible so to arrange this endless network of actions, that the formation of any vegetable product

shall be clearly pointed out. I rest satisfied, therefore, with having, as I think, clearly developed the general idea.*

The so-called *internal glands* (glandulæ vesiculares, g. impressæ) must be numbered among the organs, which serve to effect *changes* in the saps that are diffused through the plant. They are spread through the whole extent of the plant, and often accumulated in great numbers. Such internal glands are agglomerations of cells, which, however, totally differ in form, colour, and other properties, from the main bulk of cells of that part in which these glands exist. In a great number of plants they are filled with ethereal oils, resins, &c. The contents of a peculiar group of cells, exposed to peculiar circumstances although these contents were originally the same as those existing throughout the plant,— must undergo a different change of constituents, and thus lead to the formation of peculiar substances. These glands are largely found in the species of the genus Citrus, in Ruta graveolens, and in many other plants.

In some plants we frequently meet with a few cells which contain a peculiar substance, entirely different from that in the surrounding cells, a substance, therefore, which is produced by a peculiar transformation in a small and secluded group of cells. Instances of this kind have been most distinctly observed in phanerogamic aquatic plants. These plants contain isolated cells, filled with a coloured substance, so that amidst the bulk of the cells a few have a red or blue colour, whilst those immediately adjoining are colourless, although in some instances the next are also more or less tinged with the same colour. This peculiarity which was

* [illegible]

first observed by Link in Lysimachia palustris, has since been more closely investigated by others. The colouring matter of these cells in Lysimachia palustris is a very finely divided, reddish-yellow and resinous powder, whilst the cell itself is much larger than those around it. Meyen states, that the resins which are extracted from the different species of Aloë, are contained in similar cells; these resins cannot exist in the milk vessels, because in these plants they are wanting, but they are enclosed in elongated cells, adjoining the spiral vessels. The form of these very long cells is not an effect but a cause of their contents, for in young plants every cell contains in most cases but a single globule of resin, the remaining space being filled with ordinary sap. When the plant becomes older, the quantity of this resin is simply increased; but the cell retains its original form. This formation of resin, therefore, can be only attributable to the protracted stay of the fluids in these long cells.

The roots of Valeriana officinalis and V. Phu contain similar globules of resin in the cells near the epidermis; the more interior cells being without any resin and filled with starch. This is a peculiarity, which is probably nothing else than an effect of oxidation produced by the air.

The thick-walled, elongated and frequently punctated cells (*pros-enchymatic* and *pleur-enchymatic* cells) have a totally different influence upon the contents of the cells, from the parenchymatic (or merenchymatic) of which I have just spoken. The *walls* of these cells constitute an important organ of secretion;—that is, the substances of which the walls are composed are of such a kind, that they produce from the fluids which pass through them, substances similar to those of which they themselves consist. The term *assimilation*, if it should at all be preserved, might be used here. These incrustations of the walls are the principal phenomena of interchange in woody plants. Here and there a single secondary product appears, but the principal substance, formed in the woody tissue, is intended to increase the intermediate layer of the woody cells; nay, this is almost the only substance that is formed here. We are unacquainted with the cause of this

uniformity, but the phenomenon is striking. The cell-walls use up nearly the whole contents of the cells, all the solid substances that are supplied to them in a state of solution, and these they convert into intermediate woody matter, with disengagement of oxygen, and evaporation of water. This chemical transformation, this production of wood, is the chief means through which the office of the vegetable kingdom —the withdrawal of carbonic acid from the atmosphere to prevent its accumulation—is performed. The cell wall of cellulose is surrounded by a thin membrane, which resembles the former in the property of remaining un-incrusted. Between these two membranes a substance is deposited in layers of which the quantity continually increases; and by this substance the membrane or cellulose is continually pressed inwards so as to render the cavity of the cell smaller and smaller (see p. 469). This is therefore a phenomenon of true apposition, which may be classed with crystallisation (p. 89).

2. *Of the Vascular Tissue.*

In plants we distinguish in the first place spiral vessels and milk vessels (vasa propria, v. laticis). The function of the spiral vessels is still a matter of doubt. They are full of sap in spring, when the whole plant is replete with fluids; yet they do not serve for the conveyance of liquids. On the contrary, they contain air, in which, according to Draper's analysis, there exists a much larger proportion of nitrogen than in the atmosphere. This nitrogen is derived from atmospheric air, which has been secreted in these vessels by evaporation, and of which the oxygen has for the greater part been used to oxidise the adjoining substances.

The contents of the vessels that convey liquids, are very different in different plants and parts of plants. At present, however, nothing can be said of this with certainty. It is a matter of great importance to the doctrine of the transformation of vegetable substances, to ascertain how these vessels commence and terminate. The sap vessels of the plants,

which are filled with peculiar fluids, originate in the roots, from which they ramify through every part of the plant; but we do not know where they end. It is likely that they terminate at various places.

The communication between the sap vessels and the cells, alongside of which they are placed, is kept up through their walls, in the same manner as between the cells themselves. They establish a communication between the contents of cells that are far distant from each other; the fluid in these vessels being at the same time preserved from undergoing the manifold alterations, which are the necessary consequences of the endosmotic interchange between the contents of the several cells. The contents of these vessels, however, cannot be conveyed through them totally unchanged, because the little channels, when placed in circumstances which will be subsequently referred to, often contain very complex mixtures, which cannot remain in mutual contact without being changed.

If the roots absorb a clear liquid, entirely free from any substances *in* suspension—which may be concluded from the experiment of Payen, previously mentioned,—and if this liquid becomes turbid while rising in the sap vessel, then it must have on its way received substances that are insoluble in water. These substances have been produced within the vessel: in Chelidonium, for instance, it is a gum-resin. A liquid, passing through a tube that exercises no chemical action, cannot be chemically changed by this tube. Hence this chemical change must be an effect either of a transformation of the substances in the sap vessel itself, or of chemical alterations, produced by the sap in the cells, by which the vessel is surrounded.

We must bear in mind, that from these sap vessels, enclosed in cells, there is a continual lateral transference of liquid into the cells, which is affected by the same cause that makes the liquid rise from one cell to another, viz. endosmose. Thus the sap vessels are continually losing part of their fluids. But in like manner they receive fluids from other cells, alongside of which they are placed. The mutual entrance and emission, therefore, of the clear liquids in the

cells, and originally also in the vessels, must be the cause of the production of the insoluble particles, which are usually found in the sap of the sap vessels. But the same cause must give rise to several other changes, that are not characterised by the production of insoluble particles. Although, therefore, the sap vessels thus cause a slower and less active chemical change in plants than the one which takes place within the cells, yet on the other hand they may produce an increased interchange, owing to a mutual relation between the several liquids of the same plant, which is different from what can be established by the communication between the cells alone.

To give a clearer idea of the way in which a sap vessel may influence the interchange of substances, and cause the formation of new products, we shall indicate the small differences produced in the contents of a row of adjoining cells, along which such a vessel is placed, by the letters *a*, *b*, *c*, &c. When *k* and *i* interchange contents endosmotically, the result in the first instance is the mere mixture *k i*, but secondly a chemical product from the *action* of *k* upon *i*, and *vice versa*. This chemical product I shall call *p*. After the interchange has taken place, the contents of the lowermost cell is no longer *k*, but *k*, *i*, *p*, and in the second cell the contents are then no longer *i*, but *i*, *k*, *p*. What the second cell exchanges with *k* is not entirely *i*, but *i*, *k*, *p*. And this proceeds in the same manner through all the superior cells.

This shows the possibility of a continual increase of new chemical products, as the mutual endosmotic action proceeds.

When a vessel is placed alongside these cells, there is additional opportunity for new changes. *Without this vessel*, *k* has no other communication with *a*, than through *all* the intervening cells—by which in this small number of cells a *mixture*, and likewise a *chemical product* of the mutual reactions of *k*, *i*, *h*, *g*, *f*, *e*, *d*, *c*, *b*, *a*, are formed. But this vessel being present, a direct communication is established with all the adjoining cells. The compounds indicated by *k*, *i*, &c. en-

ter into this vessel, whilst the contents indicated by the letter *D* leave it. Thus in this vessel there are formed a mixture and a chemical product of *D*, *k*, *i*, &c.; and again in each adjoining cell a mixture and a chemical product of *D* and the contents of *the whole* of the adjoining cells.

Whatever promotes the mutual communication of the constituents of a plant, will at the same time increase the multiplicity of the products; and therefore the variety of the latter must be much more limited in cellular than in vascular plants.

As the system of sap vessels becomes more complicated, it will emit into the cells a greater variety of substances, and *vice versa*, and in the same ratio these substances must have a greater chemical influence upon each other; in other words the transformation of matter must increase, and with that the number and variety of the peculiar constituents of the plant.

These are the grounds upon which I consider myself warranted in considering the sap vessels, in a chemical sense, inactive, in so far as they themselves undergo no change, except an incrustation of their walls, and can produce no change in the contents. I therefore consider them merely as instruments through which the saps are transferred toward the cells, they receiving in their turn part of the contents of the latter.

3° *Of the Sap of Plants.*

The hope of being at length enabled to explain the functions of the vegetable kingdom, will only be realised when we know both the liquid contained in the cells, and that which moves through the plant in peculiar vessels, supplying the materials by means of which every change in the plant is effected.

In plants, there is not one single circulating liquid common to a great number; but of this liquid there are probably as many varieties as there are families of plants, producing the same substances. Nay, what is more, that liquid differs not only in every part of a plant, but even in every elementary tissue; that in the flower being different from that in the leaf, that in the stamens from that in the pistil, that in

the anthers from that in the filament, and that in the pollen from that in the anthers.

The great number of analyses of different parts and saps of plants, undertaken either for medical or technical purposes, can therefore afford but little, and often no information whatever, respecting the physiology of the plant, the knowledge of the change of materials that takes place within it, and the functions of the plant as dependent upon this change.

How could we expect to become acquainted with the chemical changes which the food undergoes in the intestines of an animal, or with digestion, if, after having deprived the animal of its head, legs, and breast, we analysed the belly with all that belongs to it? And yet this is essentially the way in which the chemical analysis of plants has hitherto been performed. This is the very reason why the physiology of plants is so far behind that of animals.

The vegetable saps must first be distinguished into those of the cells, and those of the sap-vessels. This clearly follows from what I have advanced in a previous page. Nothing is known of the saps enclosed in the cells alone. We have some idea of that sap only, from which the young cells are formed, and which is known by the name of *Cambium*. From the great difficulty of obtaining separately either the saps of the cells, or those of the vessels, we are obliged as yet to examine and consider them together.

Immediately after they have passed from the first into the second cell of a fibril, they have ceased to be what they were in the first cell, and they change more and more as they pass from cell to cell. This process we see going on in increased degree throughout the whole plant, so that in every horizontal section, taken at different heights, the liquid is of a different nature. We must not, however, too rashly ascribe this difference to one single cause.

Knight found that the sap of Acer plantanoides, collected close to the ground, had a specific gravity of 1.004; at two metres above the ground it became 1.008, and at four metres 1.012

The sap of the elder tree has an acid reaction, and is of a

sweet taste. Besides water, it contains sugar, extractive matter, acetate of lime (?), acetate of potash (?). Mixed with yeast, it yielded alcohol.

The beech (Fagus sylvatica) yields in April a reddish liquid, which has a weaker acid reaction, and contains acetate of lime (?) and acetate of potash (?), extractive matter, tannic acid, acetic acid (?), and gallic acid.

1028 parts of the sap of the elm tree, collected in April, yielded 9 parts of acetate of potash (?), 1 part organic matter, and 1 part carbonate of lime (Vauquelin).

Regimbeau found in the sap of the vine bitartrate of potash, tartrate of lime, mucilage, and free carbonic acid.

Riat, who has examined many vegetable saps for sugar, has found this to exist in a great number of them, and in two different forms, viz. as cane and as grape sugar. He found, moreover, a gummy substance (dextrin) and an animal substance (vegetable albumen), but he has not directed his attention to the other constituents.

Rambuca guaduas—a plant from the tropics, of the family of the Gramineæ, having between its joints large cavities, which are filled with a fresh and clear liquid, scarcely differing in taste from water—contains, according to Boussingault, almost nothing except pure water, with a trace of sulphates and chlorides, a very small quantity of organic matter, and some silica.*

But the saps of a great many plants contain so much sugar that they yield by fermentation a kind of wine. To these belong the birch, the Cocos butyracea, &c. It is well known that a large quantity of sugar is contained in the sugar cane, Arenga saccharifera, and other plants.

Langlois has examined the sap of some plants. That of the vine, collected on the 30th March, had an acid reaction: baryta water indicated the presence of carbonic acid, oxalate of ammonia that of lime. Even a mere heating was sufficient to disengage carbonic acid. Three kilograms left on evaporation a residue of 7 grains, from which 0.45 grains

* Economie Rurale, 1. p. 123. See further Boussingault, on other vegetable saps.

of tartrate of lime were separated during evaporation. He obtained quantitatively from 1 kilogr. 10 cub. cent. carbonic acid, and in the fixed residue 1.25 tartrate of lime, 0.02 nitrate of potash, besides albumen and small quantities of other substances, not further determined, but no malates.

The sap of the nut tree, collected at the end of April, contained free carbonic acid, vegetable albumen, a gummy substance, fatty matter, lactate of lime (?), lactate of ammonia (?), lactate of potash (?), malate of lime, chloride of ammonium (salammoniac), nitre, and sulphate and phosphate of lime.

The sap of the linden tree, collected in June, contained cane-sugar, vegetable albumen, a gummy substance, and some salts, among which were sal ammoniac and acetate of potash (?). (Comptes Rendus, T. 17, No. 11.)

Schultz (Flora, 1842, p. 49) has examined the fresh sap of Betula alba, Acer plantanoïdes, and Carpinus betulus, collected at different periods in spring. According to him, the sap from the wood contains at first dextrin, which he compares with the dextrin from starch, and then sugar. This is in most cases grape sugar, and when cane sugar is present, as in the maple tree, it is still mixed with grape sugar.

The ammonia, which Schultz produced by treating the sap of the birch and maple tree, evaporated to the consistence of syrup, with potash ley,—may have been partly derived from the albumen, as in many other experiments of a similar kind. It is impossible to prove in this manner the presence of ammoniacal salts in plants, although it may admit of no doubt that these salts occur in many vegetable saps.

Besides a very large quantity of water, there are a few substances which appear never to be wanting in the sap of cells, viz., albumen coagulable by heat, dextrin, and the soapy matter of Scheele. With these are united the inorganic salts, absorbed from the soil, and the salts of ammonia, which have either been produced from apocrenate, crenate, &c., of that base, have existed in the soil in the same form as in the sap, or have originated from the decomposition of part of the protein. These are generally all the ingredients that are found, and we do not, therefore, go too far in assuming, that there

are three principal ingredients that require peculiar notice, viz.: dextrin, soluble vegetable albumen, and the soapy matter of Scheele.

4° *The course of the Ascending Sap.*

Magnal first employed, in 1709, coloured liquids for showing the ascent of the saps in plants; a method previously made use of in human anatomy. This could not, in the case of plants, be performed by means of injections; but as the living plant itself draws up coloured fluids, this afforded a natural auxiliary to trace the direction which the liquids took within the plant. For this purpose he selected the coloured liquid of Phytolacca decandra. Duhamel and Bonnet used an infusion of madder, and Hedurg one of logwood. Hill employed an infusion of cochineal, and also a solution of acetate of lead, which, having entered into the plant, became distinctly perceptible, on immersing the plant in sulphuret of ammonium. Breant forced antiseptic liquids into wood, with the view of protecting it from decay, and Moll of Rotterdam afterwards successfully used creosote for the same purpose.

The last-mentioned experiments, viz., the forcing liquids into wood by pressure, could not be made with any watery liquid, as is shown by Kyan's liquid, which is a solution of corrosive sublimate in water. As this solution does not penetrate into the wood, it can only serve—although the result perfectly answers the purpose—to counteract decay occasioned by external influences. When oily fluids, such as creesote, are in certain directions pressed into the wood, they extend to other parts by capillary action, and thus the wood becomes at last thoroughly impregnated with them.

The experiments that are especially worthy of notice, in one point of view, although they are chiefly made for a technical purpose, are those of Boucherie.* He employed the so-called pyrolignite of iron, viz., crude wood-vinegar, in which rust of iron was dissolved; and this liquid he

* Ann. de Chimie et de Phys. T. 74, p. 113.

brought into contact with the stems of trees in such a manner that the latter should be penetrated by it. He placed the bottom part of newly cut stems in a solution of this salt of iron, and traced it in the stem and even in the leaves of the tree. A poplar 28 metres high, with a diameter of 40 centimetres, placed in the solution in this manner, absorbed in six days 3 hectolitres of liquid. Instead of sawing through the stems, and then placing them in the liquid, he afterwards left them in the ground, and bored holes in the stem above the root, which were kept constantly filled with the liquid. He thus obtained his object equally well. In December and February the liquid made little progress; but in the spring, the summer, and especially in autumn, it ascended very much. In winter, therefore, the saps are not wholly stationary, although they always ascend much less than in the other seasons, except in the case of evergreen trees, such as the Coniferæ, for in these the ascension during winter, although less than in the other parts of the year, was greater than in trees that had lost their leaves. In stems of which the branches have been removed, but the top with its leaves left, the rising of the liquid was always great. In general this ascent is stronger, the sooner after the cutting of the trees the experiment is made. Boucherie saw it still going on with energy after 36 and 48 hours, but after ten days it had ceased.

It appears from these experiments of Boucherie, and those of others before him, that coloured liquids ascend neither through the epidermis nor through the medulla of ligneous plants, but always through the woody part,—chiefly through the new wood, but likewise through the older part. Boucherie, however, observed, that in the centre of woody stems there always remained a kernel of a certain diameter, which was not penetrated by the liquid. This part, therefore, in the living plant, likewise, has ceased to receive accessions of liquid, and remains as an inactive body, placed as it were beyond the vital action of the plant. If that part of the wood which is penetrated by the pyrolignite of iron, is to be called albumen, then three-fourths of the diameter of the stem must

in general be called albumen. The absorbed liquid permeates three-fourths of the diameter of the stem, and on an average one-fourth remains unaffected. In branches, the liquid penetrates the whole of the wood, and in those of herbaceous plants the entire woody tissue.

Hales observed that branches of apple trees, of which the bark had been separated, absorbed coloured liquids through the wood as well as if the bark had been left on. Decandolle, on the contrary, remarked that branches of an elder tree, placed in coloured liquid with the bark remaining, were not coloured in the wood.*

These experiments sufficiently prove that the liquids extracted from the soil by the fibrils, are transmitted to the woody part of the plants, by which they are taken up and transferred to the extremities of the plant, even into the leaves, and also into the flowers and fruits.

It has appeared from observation, that by the ascent of these fluids they penetrate both cells and vessels.

Boucherie's experiments have been repeated by Mohl (Bot. Zeitung, 1843), who placed living trees, previously sawn off, in pyrolignite of iron. The stem of a birch became entirely coloured; but in that of an oak tree only the eight exterior rings were so, whilst the medullary rays and part of the vessels became brownish black. When oblong and transverse sections of the latter were subsequently placed in a solution of ferro-cyanide of potash, and then some acid added, both the contents and the walls of the cells and vessels became beautifully blue.

Notwithstanding these experiments, made by this celebrated botanist, those of Boucherie still remain unavailable for vegetable physiology. The fact that a liquid which is partly of an oily and partly of a watery nature, penetrates through organs, which in the natural condition of the plant are impermeable to watery saps, may easily be accounted for from the facility with which creosote, eupion, &c., which are all constituents of the so-called pyrolignite of iron, are absorbed by capillary action, and so may permeate substances that cannot

* Phys. Veget. Tome I, p. 83.

be penetrated by watery fluids alone. For although the saps of plants ascend through the vessels alone, yet the lateral motion through the cells might have been here much increased by the empyreumatic oils, just mentioned, and this strong lateral motion might not take place at all in the watery saps of the living and growing plant. Pyrolignite of iron, therefore, is not a fit liquid to employ with a view to throw any light upon the ascent of saps through cells or vessels.

Rominger (Bot. Zeitung, 1843) has made new experiments upon the motion of saps in plants. He first caused them to absorb ferro-cyanide of potassium, and then he cut them off and laid them in a solution of oxide of iron. He thus found that cellular plants have no peculiar system of cells for the conveyance of saps, and that in all vascular plants the sap ascends through the vessels and not through the cells. We shall now show that this conclusion must necessarily be incorrect.

Boucherie found that when holes were bored either in the wood of trees placed in an erect position, or in the inferior part of the stem, the liquid which he poured in entered both into the cells and vessels. This experiment cannot, therefore, any more than the former, serve perfectly to solve the questions which are so important to physiology; for when vessels have been bored through and filled with liquid, they must give passage to this liquid, no matter how it be presented to them. Boucherie observed, that when the liquid had been introduced from above, it flowed very readily from an opening made at the bottom, and made use of this to wash out several substances from fresh trees, and to replace them by other saline solutions of various kinds. In this manner he was able in the month of December to expel from the stem of a beech tree, having a height of 16 metres (about 64 feet), and a diameter of 86 centimetres, in a period of 25 hours, 3060 litres of sap, and to replace it by 3210 litres of pyrolignite of iron. This sap was obviously derived from sap-vessels, which had been cut through when the openings were made, and which merely, according to the mode of replacement, had lost one liquid to take up another in its place.

This gives us little explanation regarding the manner in
the saps ascend from the soil. The experiment shows
ever, that in beech wood there are actually continuous
running from above downwards, and capable of con
fluids, and that, therefore, these tubes must certainly be
into account in investigating the motion of liquids ar
change of materials which this motion produces.

The experiments and observations on the motion of t
made by Brücke (Poggendorff's Annalen, Bd. 63, p. 177,
are deserving of much attention. He has observed mo
tinctly that in spring the whole ligneous part is fille
sap, before the spiral vessels contain any liquid. The
sels are at that time filled with air; and not until every
part of the plant is, as it were, overflowing with liquid, d
receive so much of it that they become also full, the air
at the same time expelled from them. All the cellula
ties, therefore, take up the liquid which the plant a
from the soil. This liquid is carried upwards throu
these cavities, and not exclusively through the vessel
certainly not through the spiral vessels, to the exc
of all the other parts,—a conclusion to which we are nat
led even from the simple conception of the structure of p
It is from the cells that the sap is at length forced int
spiral vessels, and this takes place with such force t
may even flow out of the spiral vessels,—it being, ther
not necessary to consider this as a proof, that the asc
the sap takes place through the spiral vessels. As th
ral vessels are generally wider than the surrounding
they cannot absorb the saps by capillary action, and
fer them into the cells; but on the contrary the cells
carry up the liquid, and when they themselves are ove
ing, they may transfer it into the spiral vessels, out of
it may then flow, when a transverse section of the pla
made; or when no transverse section is made, it may in
manner be carried upwards to the higher parts of the pl

This conclusion, based both upon the old observatio
Hales and the more recent ones of Brücke, is of very
importance, for it serves as a key to an important phen
non of vegetable life.

The primary cause of the motion of the sap in plants in spring, is undoubtedly the chemical change of the substances that have been prepared in the preceding year. Among these substances we must chiefly notice the starch which is present in the wood, and which on the first warmth of spring is converted into dextrin and sugar. As the starch, whilst being converted into dextrin, swells and absorbs water, an increase in the quantity of water becomes a necessary consequence, and the roots, through an endosmotic action, begin to absorb liquids from the soil. Meanwhile the leaves begin to be developed, and as soon as these present part of their surface to the atmosphere, these humid laminar expansions sustain the evaporation which was already going on from the young and juicy branches, nay, from the entire epidermis of the stem. In this manner the continual supply of fluids from the soil is kept up by these combined actions, as long as the temperature and the hygrometric state of the atmosphere are favourable. Finally, in winter, after the leaves have fallen off, and the change of materials within the plants has nearly ceased, the water of the stem and branches continues, nevertheless, to evaporate; for it was observed long ago by Muschenbroeck, that even from ice evaporation takes place. The plant being then as it were dried up, it is prepared for the first absorption of liquid in the next spring, which takes place as soon as the elevated temperature of the air causes the first traces of change of materials to appear within the plant.

We may, therefore, with certainty, draw this general conclusion—that the motion of saps in plants takes place through *all* their parts which are not filled with fats, oils, or resins,—that is, not covered with perfectly impenetrable layers,—and chiefly through the narrowest parts. Only when these saps are in great abundance—and, therefore, only during a short period of the growth of the plant—do they move through the spiral vessels in consequence of their being forced into them; but their transference from one part to another is effected through the cells, the vasa propria, and also through the milk vessels (vasa laticis) in those plants which contain them.

As regards the absorption of liquids by the plant in summer, we have to remark that the quantity of the liquid thus taken up is proportioned to the temperature of the atmosphere, the diameter of the stems or stalks of the plants, and the surface which the leaves expose to the air. In hot days this absorption is much more energetic than in cold; thick stems absorb much more than such as are thinner; and a plant which, *ceteris paribus*, presents to the atmosphere a double surface of leaves—a plant, for instance, that has double the quantity of leaves—will, in an equal period, absorb through its roots a double quantity of fluid.

These observations lead to the following conclusion: that both the conveyance of the water through the stem and its evaporation through the leaves are the first conditions which determine the absorption of the water that is present about the roots. If, therefore, the facility of passage through a number of plants be the same, the quantity of water absorbed depends on the evaporation through the leaves.

This is not contrary to the observations of Savé, viz. that in the spring a greater quantity of sap moves through the plant, and must therefore be extracted from the soil, than in the summer or autumn. It is true, that the temperature of the air is lower in spring than in summer; but it is equally true, that in the preceding winter the ascent of liquid from the soil had been impeded, and was continually decreasing in the previous autumn, whilst the evaporation continued. At the first heat in spring, therefore, before any leaves are produced, a great quantity of water must be absorbed from the soil, and carried through the plant, in consequence of the evaporation that takes place from the whole surface of the latter. In addition to this, the development of the bud commences, which uses up the adjacent fluids. Thus the parts next to the bud, are deprived of liquid, and this promotes the ascent of fluid from the lower parts, and finally from the soil through the roots.

It would, therefore, be incorrect to consider the evaporation of water from the leaves as the only cause by which the absorption of liquid from the soil by the plant is effected.

for whence could this ascent originate in the spring, before the leaves are produced?

But if it is a fact, that in summer the evaporation is the first requisite for this ascent of the sap, as appears from what has just been mentioned, in spring the development of young parts, and their need of water, without which they cannot be properly developed, are the first causes of this ascent. We must, however, here distinguish between two different causes, the one connected with the solid substances that are held in solution by the sap in spring, and the other with the water of this sap itself.

The influence of the former may be simply presented in the following manner. If we had two vessels, each containing a solution of the same salt, but of different strength, and connected with each other by means of a siphon, and we saw the crystallisation of the salt commence in the one solution, whilst the other was still too dilute, we should at the same time perceive, that the weaker solution passed over through the siphon into the one that was originally stronger, in consequence of the dilution of the liquid from which the crystals were separating. A similar action takes place at the development of new cells in spring. Whilst cellulose is forming from dextrin, the sap necessarily becomes more diluted, but the disturbed equilibrium is restored by an exchange of materials between the contents of the cells, which are in immediate connexion with each other.

But the cells that are newly produced require liquid to fill the space formerly not occupied by the new part. The vesicle now formed, and not existing a little while ago, requires liquid, which can only be derived from the neighbouring cells. As these cells are thus being emptied of sap, they must have this loss filled up from below, and ultimately from the soil.

As long as these new cells continue to be developed, this cause of the upward motion of saps continues to act, and becomes more and more energetic by the development of new parts. When at last these parts are completely developed, the ascent of liquid from the soil is effected by evaporation alone

But this evaporation itself commences in spring, immediately after the buds are disclosed, and although their parts are then small, yet they are tender, and consequently liable to a much stronger evaporation than the surface of leaves of equal size in summer. As the young cells still contain but a small amount of solid substances, they afford greater facility for the transmission of water into the atmosphere, than the older leaves. The evaporation through the leaves in spring, therefore, is an early and powerful cause of the absorption of food from the soil; and consequently we need not have recourse to special and unusual causes to explain this rising of the sap in spring.

The cause of the dilution of saps, above mentioned, viz. the conversion of dextrin into cellulose, is opposed by another of great importance. As soon as the leaves begin to be developed, carbonic acid and water are converted by them, through the influence and co-operation of organic substances, into products consisting of carbon, hydrogen, and oxygen, a process which is attended by the elimination of oxygen. Solid substances, therefore, are formed within the young cells of the leaves. These solid substances require water to become diluted, which is effected according to laws to be detailed below. Whilst this dilution is going on, a rising of saps must necessarily take place from one cell to another, and so through the whole plant.

Although, therefore, the dilution of the sap, in consequence of the conversion of dextrin into membranaceous bags of cellulose, and the formation of new solid substances from the carbonic acid that is absorbed by the leaves, are two actions, which, to a certain degree, compensate each other, yet the final results of both these functions are the increase of the number of cells, the filling of these cells with liquid, an increased evaporation through the larger surface of the growing leaves, and finally the rising of sap from the soil.

5° *On the Descent of Solid Substances in the Rising Sap.*

One of the very important sources of the formation of complex combinations in plants, is the meeting together of two

very different kinds of nourishing substances in two opposite directions. These substances are the organic ammoniacal salts and inorganic salts of the soil, which along with water impregnated with carbonic acid, enter through the roots, whilst carbonic acid itself enters through the leaves. If it is true, that the chief cause of the production of new and peculiar combinations in the interior of plants must be looked for in that unlimited multiplication of the small spaces or apparatus, in which the substances are enclosed, which they constantly leave and re-enter, to which something is continually added, and from which something else is taken,—if it is true, that this power of forming new combinations is really the effect of those multifarious opportunities for mixing together the several parts, then the meeting of two opposite currents of entirely different substances within the plants must cause a considerable increase in the number of products. The albuminous substance being constantly introduced from the roots and carried upwards, meets on its way with descending non-nitrogenous compounds, and whenever this happens, it has an opportunity of communicating its own state of decomposition, whilst the substance which is the cause of the de-oxidising action in plants, and which is, undoubtedly, also carried upwards from the roots, causes this decomposition to take place in a determinate direction.

If we enter deeply into the consideration how various the influences are to which the food, when introduced into the plant, is exposed, we ought, indeed, to be surprised that the number of organic groups, which are the effects of these influences, is not even greater. But what ought especially to surprise us, is, that so many generally diffused and completely identical groups, such as cellulose, dextrin, starch, &c., can exist in plants. Nay, we should then rather feel inclined, not to call the contents of even two adjoining cells in the whole vegetable kingdom alike, but to find difficulty in understanding the variety, multiplicity, and abundance of the combinations. It is only because there are apparently limits to the allotropic state of the elements, and that their combinations

only exchange with each other by multiples of whole
bers, which do not go beyond a certain limit, that the
table groups are not unlimited in number.

In order to give an idea of the phenomenon that is n
at the head of this article, I shall select as an illustr
the formation of wood; but, before doing so, I shall
the various views regarding it, which have recently bee
vanced.

Botanists have written much on the manner in whic
formation of wood in plants takes place.* Dupetit Th
has presented it in the following manner, although the
nomer De la Hire had before him expressed the same
Buds are true germs of new plants. The seed, when p
in the ground, makes its roots enter into the soil, and ele
the opposite part into the air; a bud does the same, for i
velopes its roots downwards into the parent plant, and
duces leaves and flowers in the opposite direction. The
ter fall in every season, which predisposes the plant
new development; but the former remain. The roots o
buds extend themselves along the interior of the base, thr
the entire stem of the parent plant into the soil, and as
process is repeated by every new development of buds, a
layer of roots of buds is every season deposited upon the
terior of the bark. In other words, this process gives ri
the familiar annual rings of the wood, and at the same t
to the yearly extension of the roots of the parent plant thr
the soil.

This idea has been considerably enlarged by Gaudich
According to him, and in accordance with a very general
ception, plants contain an ascending and a descending
The latter moves between the bark and the wood, and
duces cells, placed horizontally, that is, in the direction of
medullary rays; whilst from this same descending sap betw
bark and wood, vessels and ligneous cells are produced
vertical direction downwards.

* See the warm controversy between Mirbel and Gaudichaud in Co
Rendus, 1843, p. 1214; 1st Series, p. 1235 and p. 1379; and also in An
des Sciences Naturelles, 2d Ser., Tome 20.

Leaving for a moment the question regarding an ascending and descending sap—it must be said of the above idea, that it is in accordance with many facts. If, for instance, a string is tied round a stem, a swelling of vascular bundles is produced above the string, and this could only have been caused by descending substances.

Against this idea several arguments have been advanced, one of which is the following. Whilst the buds emit bundles of vessels, as their roots, downwards between the bark and the wood, it is obvious that, if this were the cause of the formation of wood, these bundles ought to be most highly developed near the buds, and that thus the branches that were last developed ought to present a much more abundant formation of wood than the stem, which is far removed from the buds. But we know that this is contrary to fact. Further, in the process of grafting and splitting, the wood of the graft ought to be homogeneous with that of the stock, after the joined parts have properly grown together; that upon which the grafting has been performed, should be identical with the scion. But this is not the case.

The Abies pectinata, when sawn off some feet above the ground, continues for many years to increase its stem, and new layers of wood are deposited around it, as when the tree was uninjured. (Dutrochet).*

Have we a right to conclude, from what is here stated, that in the normal condition of a plant, the *sap*, from which wood is formed, are actually carried downwards between the bark and wood, and that when the bark is in a state of disease,—for instance, in consequence of a circular incision,—the operations are performed in new channels, as takes place in animals when large arteries are tied? I believe that *nothing* of all this has been proved by evidence. When we speak of the ascending or descending motion of *sap*, this ought not to be deduced from phenomena and products of secretion, but from observations of the motion of the *sap* itself.

I am further of opinion, that we have no ground whatever to maintain, that the new woody rings are roots of the buds,

* Les Elemens d'Hist. Nat., Botan. par M. A. de Jussieu, P. I. p. 271.

but only that *substances* are carried downwards, from which cells are produced in the medullary rings and vessels in a vertical direction, and that when the bark is in a state of disease, these productions are formed in some other manner, as yet unknown.

In order to have a clear idea of the downward motion of the substances of the food, we must make a due distinction between the actual descent of *saps* or *liquids*, and that of *substances* which these saps hold in *solution*. It is a matter of surprise, that nobody has yet thought of making this distinction. It appears to me, that thus several questions might be solved by one single answer. The descent of *saps* or liquids in the plant is not supported by one observation, and we have therefore no ground for accepting it as a fact; whilst many unquestionable observations prove that there is a descent of *substances* held in solution.

All the phenomena, adduced by Dupetit-Thouars and Gaudichaud, merely prove that there is a descent of *substances*, dissolved in the sap. Referring to the known phenomena of endosmose, it is obvious that these are generally attended with a mutual exchange of constituents between the liquids that penetrate the membranes.

If two substances, A and B, each dissolved in water, are to act upon each other by endosmose, part of A will be moved towards B, and at the same time part of B towards A, and the products will be A B and B A.

If there is really an endosmotic action in plants,—a fact which nobody will call in question,—if the roots do actually absorb A from the soil, and the leaves B from the air, then there must be produced throughout the plant various proportions of A B and B A; and although the whole of the *sap* of the plant, that is, the whole of the watery *liquid*, rises upwards in the plant, yet there must be a downward motion of B and of all its products.

This is, I think, the light in which we must view the phenomenon of the formation of wood and many others, originating from the two opposite sources of the nourishment of plants, the soil and the air. The greater part of the carbonic

acid being derived from the air, and thus supplied from above, and this being the material from which the largest quantity of solid substances is to be prepared, it is consistent with *appearances* to assume, that the vegetable *sap*, which is to supply solid substances, is carried from above downwards. Yet the water of the thin watery liquid *ascends*, and within the plant *an exchange* takes place between the organic food and the saline solution from the soil, and the carbonic acid from the leaves with its products. This exchange is performed endosmotically, and in innumerable directions, and thus the appearance of a downward motion of solid substances must necessarily arise.

We have therefore no ground for asserting a circulation of the saps from the roots to the leaves and back again; on the contrary, we have reasons for denying this. The idea that the food absorbed by the roots is elaborated in the leaves, is unfounded, this being only applicable to the small quantity of carbonic acid which has been taken up along with the rain water, and cannot be decomposed in the dark.

It is necessary, however, to dwell a little upon one or two apparent contradictions to these views. In the first place, it might seem unnatural, that whilst the main bulk of the food is introduced through the leaves, by the endosmotic exchange of the contents of the various cells, the stems should be thickest near the root, and should thin out towards the top, even when there are no branches. But this very fact is confirmatory of the remarks which I before made, viz: that the substances which are to give the impulse to those about to be exchanged, must be derived from the soil. Before the substances, descending from the leaves through the stem and branches, can assume a definite form—for instance, that of woody cells, they must receive an impulse or impression from other substances which are in a state of transformation. As the latter ascend from the soil, the formation of new cells must be most rapid and energetic there, where the largest quantity of these nitrogenous bodies exists; that is, at the foot of the stem. Consequently, the stem must be thickest below, and thin out towards the top.

In the spring, a great part of these nitrogenous substances in the stem is separated from the sap, and is deposited in the cell walls in an inert state; but in the course of the summer the same nitrogenous bodies accumulate higher and higher in the stem, and thus reach the foot of the branches. Here they remain till the next spring, and are then again dissolved in the sap that rises from the soil. In this manner, a larger remainder from the former year is ready at hand, to be immediately transferred into the leaves, there to excite action—that is, to form new products from the carbonic acid which the leaves absorb.

But it must, moreover, be borne in mind, that although the carbonic acid were instantly converted within the leaves into a solid and soluble organic substance, it does not follow from this, that this solid substance is immediately capable of being converted into cells or wood. Consequently,—even although the whole of the food were absorbed by the leaves, and nothing from the soil,—there would still be no reason why this stem should be thin, and the branches very thick.

Setting aside the questions regarding the morphologic development of the wood, I consider it as established,—

1st. That the sap of plants is everywhere ascending, and never descending.

2d. That in its upward movement it carries along the protein, which can only be produced from the constituents of the soil, but not from what is absorbed by the leaves.

3d. The main bulk of solid substances, however, is formed at the other extremity of the plant, viz: the top; at least their source is there.

4th. By endosmotic exchange, from above downwards and *vice versa*, a certain portion of these solid substances is made to *descend* in the continually *ascending* watery liquid: a result which is known to be inevitable from the laws of endosmose.

5th. These descending substances give rise to new cells, new products, and are the chief materials from which wood is formed.

6. *On Milk-sap Vessels and Milk Sap.*

The description of these vessels, and the observation of their contents,* we chiefly owe to Schultz, whilst his views have been opposed by several others, especially by Treviranus. The latter did not deny that plants possess a peculiar system of tubes, which serve for the conveyance of sap; but this sap, which Schultz called vital sap, nourishing liquid, was considered by Treviranus as a secretion; the former ascribed to these vessels a chief function, whereas the latter contended that their importance in plants is very secondary.

My colleague, Harting, has kindly afforded me an opportunity of seeing the motion of sap in the stipules of Ficus elastica, in the petals of Papaver orientale, and in some other parts of plants; but on account of my limited knowledge of this subject, I must chiefly refer to the observations of others. This subject is of the highest importance in the physiology of plants. If there are really sap vessels,—if it is a fact, that in plants, as in animals, a liquid circulates,—then a new similarity between the functions of both will have been discovered; and the general principles upon which secretion and nutrition, that is, the change of materials in animals, are based, are partly applicable to plants.

The sap vessels may be easily recognised by their contents. When placed under the microscope, we see them as continuous canals, while the liquid contents move at intervals, as can be readily ascertained, from a large quantity of globular or differently-sized bodies passing over the focus of the microscope. These globules are floating in a liquid, just as the blood corpuscles do in the blood, and by the great multitude they give the watery sap a milky appearance. Hence it is called milk sap. Schultz's statements regarding the nature of these globules have, without doubt, sufficient foundation. He thinks they take no part in the formation of the solid body, which is produced when the milk sap comes

* Mémoires présentés à l'Académie, 1841. Tom. 7. p. 1. and Verhand der Kais. Leop. Car. Ac., Bd. 18. Supol. 2. 1842. See Froriep's Notizen, 1843. No. 40 and 41. Annal. des Scienc. Natur. Bot. Jan. and March, 1844.

into contact with the air; but that the coagulum, which is produced under these circumstances, originates from invisible particles, dissolved in the sap, or at least not contributing to its milky appearance. These particles he conceives to form an elastic body, by cohering together, in the same manner as fibrin in the clotting of the blood. This elastic substance he calls *elastine*, and in his opinion it consists either of caoutchouc alone, or of wax and gum besides. The globules themselves are composed of waxy or fatty substances; and sometimes they flow together like little drops of oil. Ether and alcohol extract from them fat and wax; the smaller ones being completely dissolved, whilst in those of larger size the waxy contents are surrounded by a membrane, which is insoluble in these liquids.

According to Schultz, the constituents of the milk sap are caoutchouc, wax, fat, sugar, gum, albumen, and salts.

A superficial view of all this is sufficient to show that however great the merits of Schultz are as respects his observations on the sap vessels, his chemical knowledge was insufficient to enable him to give any clear idea regarding the nature of their sap; and so we are still completely in the dark upon this point. It is unquestionable that there are many varieties of sap in the milk vessels. In some of them the globules are actually caoutchouc, of which they consist almost exclusively; by the contact of the air they close up and form a real coagulum. Faraday has proved that this is the case in the kind of milky sap from which the caoutchouc is obtained. In many other plants caoutchouc is also present; opium, for instance, contains so much of it that, if not too dry, it actually becomes elastic. But in a great number of milk saps we find not even a trace of caoutchouc; and I therefore consider the statements of Schultz as incorrect for these three reasons: 1st, that the globules of the sap may be real globules of caoutchouc, and need not always consist of fat or wax; 2d, that they may contain a variety of other substances besides, regarding which no investigations have been made; and 3d, that in many saps not a trace of caoutchouc exists, and that consequently the coagulum which is formed

in these cannot always be named *elastine*. By the application of a few re-agents, we can learn nothing about the nature of this sap, and therefore the first sound knowledge in this important department of vegetable physiology must be expected at some future time.

Mohl, however, has made important observations upon the nature of the globules.* He examined the sap of Sambucus ebulus, of which the globules are particularly large, having a diameter of 1-50th of a millimeter, whilst those of the fig tree have only a diameter of from 1-400 to 1-200 of a millimeter, and those in the milk sap of Euphorbia, Asclepias, Papaver, and Cichorium are even much smaller. The globules in this sap he found to consist of an almost soft and very glutinous substance, which could be drawn out into long threads, which could be united together by pressure, and presented not even a trace of a membrane. When stirred with a needle, the globules form one coherent and glutinous mass.

A thin layer of milk-sap, dried on the object glass, produces no coagulum, and presents nothing similar to the formation of the clot on blood. On the contrary, when this dry residue is moistened with water, the original sap is restored, and also its globules, as they appeared in the fresh sap.

When a portion of dried milk-sap is touched with the point of a needle, it throws off little fragments, like a brittle and gummy substance. In this dried and brittle residue the globules are diffused.

It follows, therefore, from these observations of Mohl, that caoutchouc exists in milk saps in the form of globules, and not, as Schultz asserts, in a state of solution or division, like the fibrous matter of the blood. The globules, found by Mohl, are insoluble in alcohol, but soluble in ether, and hence the addition of ether to a milk sap lessens its milky appearance. When such a mixture of milk sap and ether is dried it is, according to Mohl, in several respects similar to caoutchouc.

From these observations, therefore, of Mohl, it appears that the comparison drawn by Schultz, between the milk sap of

* Botan. Zeitung, [illegible]

plants and the blood of animals, between the coagu
the latter and the separation of caoutchouc from th
&c., is unfounded.

As to the motions of the milk sap, we plainly p
progressive, and, at the same time, a rotatory movem
globules, whilst the latter are moved in a direction
to that of the movement of the sap. The latter mo
depend upon external influences, but it may also a
causes that are yet unknown. Its existence is un
able. Among the causes from which it may arise
named the influence of light and heat, and molecul
tion. It seems, however, impossible at present to e
Until the causes of *Brown's motion* are cleared up, w
express any decided opinion upon that peculiar moti
cellular saps or of the latex of the sap vessels,—
which has the appearance of being dependent upon
attraction and repulsion.

The rotatory movement of the globules presents
particular, except this, thatitproves to us that these b
not spherical. We may, indeed, sometimes perceive t
are polyhedric. If they were of a spherical form, their
movement could not be perceived.

The progressive movement is, as far as I myse
observed it, of a very variable kind. Sometimes, espe
the beginning of our observation of some sap vessels,
the globules rapidly flying across the focus of the micr
The movement becomes gradually less, ceases, recom
goes on at almost regular intervals, and sometimes it
suddenly, in which cases it seldom reappears. In some in
the direction is at once reversed. Lateral currents, o
ing from the anastomoses of the sap vessels, flow i
main stream, with which they unite in a regular man

Now, the question is, whether these motions are in
spect similar to those of the blood in the capillary s
The contrary is evident from the phenomena briefly e
ated here; and the observations of Morren, Amici, an
cially those of Mohl,* make it certain that the mo

* Botan. Zeitung, 25 Aug., 1843.

these globules in plants is regulated by external circumstances: for instance, pressure effected on a leaf during the microscopic observation,—the cutting of the leaf and the flowing of the sap from the petiole,—the application of heat to the spot under observation by means of the direct rays of the sun—the endosmotic action of the water, with which the part is moistened during the observation, &c. To the influence of such external causes, we may also refer the changes of direction exhibited by the milk sap, during the course of its motion, &c.

But does this annihilate the great importance of the sap vessels and latex as regards the physiology of plants? I cannot see that this is the case. Plants are influenced by innumerable external causes, by which this motion of the sap may be maintained, and thus may a certain liquid be transferred through peculiar tubes, from some parts to others, at a great distance. In this manner a similar effect may arise in plants from the sap of the milk vessels, as in the animals from the blood, namely, a change of materials supported by a common fluid;—a change of materials, proceeding from a fluid, from which at one place something is taken, and to which at another place something is added.

To these external causes, which can maintain the motion of saps in plants, belong the heat of the sun, which affects the several parts of the leaves in different degrees; the motion of the air, even that caused by the slightest winds, and a great many others.

Although, therefore, we have no reason to assume, that this motion of the sap arises from an *organic* cause, as Schultz appears to have erroneously inferred, yet the motion itself remains a fact, and likewise the service which the sap can perform in plants.

But it is still a question, if this sap should be called *vital sap*;—for it may perform important functions, and yet these may not constitute the chief functions of plants.

It is difficult, and perhaps impossible, positively to answer this question. But if we ask, is it a function of the sap of the milk vessels, to be conveyed through active parts of

plants, and so to contribute to the change of materials, a
does it therefore not belong to the excretions of plants?—th
this question must be answered in the affirmative; for t
service it performs is certainly important for the maintena
of the change of materials, that is, for vegetable life. T
value of the latex does not depend on the absence or p
sence of periodic regularity in its motion, nor on the ca
of this motion being organic or not. Even the most irreg
motion, entirely dependent on external causes, would
prevent the latex from performing the same service in pla
as the blood of the capillary system does in animals, by
exosmotic transmission of substances into or from the ad
cent cells. Or I might rather say, it is beyond doubt that t
transmission must take place in the presence of a wat
fluid and of walls, such as those of the vessels of the lat
and although this latex may not deserve the name of *
sap, its value as regards the preservation of life in plants
unquestionable. A great part of the doctrine of Schultz
this subject may fall to the ground, yet I think that the m
important points of his theory are to be maintained, even
ter Mohl's observations.*

I conclude this brief notice of what we know regardi
the sap vessels and the latex, by repeating, that many acti
parts of plants contain narrow tubes, through which a w
tery sap, mixed with highly nitrogenised substances, may
put in motion by external influences; and that this s
serves the adjacent cells to take out of and pour into, in th
same manner as happens with the capillary vessels in the an
mal tissues.

What we know already regarding the chemical compos
tion of these milk saps entitles us to assume, that they diff
in plants of different families, and are the same in the sam
families. But we have almost no knowledge as yet of th
subject, in connection with the physiology of plants.† W
know that opium, antiar poison, and many so-called gu

* Bot. Zeitung, 1st Sept., 1843

† See further regarding the conveyance of sap in the vessels of plants, I
minger, in Bot. Zeitung, 17th March, 1843.

resins, are the solid residues that remain after the evaporation of the latex; but it would lead us quite beyond the right path, were we to draw from these individual instances any general conclusion as to the composition of the sap of the milk vessels.

Some of these milk saps have been examined by Boussingault.* He found that the sap of the fruit of Carica papaya, analysed by Vauquelin, also exists in the stem of this plant, although it is of a less milky appearance. It looks like a mixture of water and milk; but, on exposure to the air, it becomes soon coagulated. Besides a large quantity of protein, he found in it sugar, and a small quantity of wax and resin.

The sap of the Cow tree (*Galactodendron dulce*), which has been analysed by de Rivero and Boussingault, is so similar to cows' milk in appearance, that it might almost be confounded with it. Acids, however, do not coagulate it, and alcohol but little. When heated, a thin film is formed on the surface, and on further evaporation drops of oil appear, which continually increase in quantity. After the water has been wholly evaporated, a fatty liquid remains behind, in which a fibrous mass floats, and which, on being more strongly heated, gives off a smell so much resembling that of roasted meat, that no difference can be perceived between the two.

The fatty substance fuses at 140° F., and is soluble in alcohol and potash. The fibrous mass appeared to be perfectly similar to the fibrin of the blood, which, however, implies nothing more than that it exhibits the characters of vegetable albumen, according to the properties mentioned by Boussingault. It is owing to this substance, that the sap of this plant, when getting old, acquires the smell of old cheese.

In addition to vegetable albumen and a fatty substance, which had some of the properties of wax, this milk sap contained a little sugar, a free acid, various salts, and water. It is, therefore, a real emulsion, and may indeed be compared with cows' milk. The use of it as a common drink is consequently very natural.

* Economie Rurale, Tome i. p. 125

The sap of Hura crepitans is considered by Boussing as poisonous, even by mere exhalation. It has the s appearance as the sap of the Cow tree, but is a little m yellow. It contains gluten or casein, a blistering oil, an kaloid, a nitrogenous odoriferous body, salts and water.

The sap of Antiaris toxicaria, from which the upas-an poison is prepared by a simple evaporation of the water, tains, besides water,

Vegetable albumen,	16·14
Gum,	12·34
A peculiar resin,	20·93
Myricin,	7·02
Antiarin,	3·56
Sugar,	6·31
Extractive matter and salts,	33·70
	100·*

Several plants contain a milk sap, which yields caoutch Sap of such a kind, very rich in caoutchouc, may be obtai especially from Jatropha elastica, Hævea caoutchouc, Fi indica, and Artocarpus integrifolia, all plants from tropi regions. On making an incision through the bark, the flows out, which may be kept for a long time in closed b tles. When the water is evaporated, the caoutchouc rema behind with its familiar properties. Faraday found in 1 parts—

Caoutchouc,	32
Vegetable albumen,	2
A nitrogenous, bitter substance, soluble in water and alcohol,	7
Sugar,	3
Water,	56
	100

By mixing the sap with water, the caoutchouc may be wash clean from the other substances, and thus be obtained alm in a pure state.

* Natur-en-Scheikundig. Archief, Bd. 5.

Finally, opium, derived from the capsules of Papaver somniferum, by means of incisions, is also a latex, in which we find narcotin, morphine, thebain, meconin, codein, narcein, meconic acid, resin, fat, caoutchouc, gum, mucilage, extractive matter, &c.

II. On the Secreting Organs. Secretions.

Plants contain not only canals, filled with air or liquid, but also certain tubular cavities, of a less regular form, and filled either with air, or with mucilage, gum, resins, and balsams. These cavities owe their existence to the disjunction of a number of cells. The resins and balsams are products of oxidation of the ethereal oils, and hence they owe their origin to the entrance of the air into these canals; but the other substances, such as gum and mucilage, which are found in these cavities, have merely transpired through their walls. They occur as such in the cells themselves, and therefore Meyen is mistaken in classing them with the excretions of plants, and in calling these canals secreting organs.

There is nothing particular, therefore, in the existence of these substances in canals, which are sometimes filled with air,—but which ought not on that account to be distinguished from those containing ethereal oils, resins, gums, &c. On the contrary, the presence of these canals and products arises from a general cause. Formed by the disjunction of cells, they absorb air, ethereal oil, mucilage, gum, &c., according to the nature of the cells which surround them, and which force their contents into them. They may, therefore, alternately perform different functions, by alternately containing different substances. This is certainly the case with regard to those containing resins and balsams, which must originally have contained ethereal oils, the latter being, however, converted into resins or balsams, because the canals also contain, or admit of the entrance of air. The difference between resins and balsams is owing to the quantity of air admitted, for balsams are mixtures of resins

and ethereal oils, and therefore they are in a lower degree of oxidation than the resins.

The difference, then, in the substances contained in these canals, depends on the nature of the adjacent cells, or on the substances present in these cells, and on the function which they perform. Those canals serve merely to carry the said substances,—viz., gums, resins, balsams, air, &c., out of the plant. They do not perform the function of secretion, any more than the urine-bladder does in animals. This function is exercised in another part, viz., in the adjoining cellular contents. The exchange of the constituents of these contents gives rise to a new product, which, after being prepared, transpires through the walls of the cells. Transpiration is something different from secretion, from real production. The cells immediately adjoining the channels mentioned, contain the substances and expel them. The intercellular canal does nothing else than receive them, and itself increases in volume with the increase in the quantity of the transpired substances.

The difference in length of these respective canals, their comparative shortness,—for instance, those in perisperms of the Umbellata,—preventing the free access of the air, is the cause why some of them contain volatile oils and no resins; whilst, on the other hand, some ethereal oils are less liable to be transformed into resins than others. Decandolle calls them *réservoirs en coecum.*

The real organs of secretion in plants are the so-called glands, which have been examined by Link, Mirbel, Guettard, Schrank, and Meyen*. They serve either to prepare the fluids, and to remove them from the plant, or at least to perform the latter function. Some of them, however, are placed in the interior of the plants, and are called *internal glands.*

The external glands are either simple or compound. The

* Link in Philosophia Botanica, p. 231.
Mirbel, Mémoires du Muséum d'Hist. Natur. T. 9, p. 455.
Guettard in Hist. de l'Académie Royale des Sciences, 1745–1750.
Schrank, Von der Nebengefässen der Pflanzen, 1794.
Meyen in Die Secretions: Organe der Pflanzen, Berlin, 1837.

former sometimes consist of one single cell or of a few together, provided with a single hair, of which the head or extremity is the real gland. These glands are called *pili capitati*. The hairs themselves are formed from cells of the epidermis, being developed from their superior wall. They are articulated, that is to say, the cell, which is developed from the surface of the epidermis-cells, produces a second cell in a longitudinal direction; this again produces a third cell, &c., whilst at the extremity a little knot or head is formed, also consisting of a single cell, in which the real secretion takes place. This secretion may be called a change, effected in a small group of the general constituents of a plant, on its being exposed to the air within a single vesicle. The body secreted is an ethereal oil, and in some cases it contains other ingredients also, such as coloured substances. The latter may, however, be products of oxidation of the real secretion, which is separated from the air only by a thin cellular wall. This is the cause of their colour being red, blue, yellow, or grey. Sometimes these stipitated glands contain watery fluids, especially when they are present in great numbers. In this case they serve to enlarge the surface of the plant, and thus to promote the evaporation of the water. Glands of this kind are found in some species of Chenopodium; they assist considerably in the acceleration of the growth. But such glands do not belong to the true organs of secretion in plants, that is, not to those organs by which substances are prepared or secreted, *different* from those existing in the plant itself.

When viewed in this light, therefore, we cannot accede to the idea, now generally adopted, that the hairs of plants are all organs of secretion, when they contain watery fluids, and serve for the evaporation of water, and thus for the promotion of the growth (there being in the same manner procured a greater opportunity to the ascent of new nutritious liquids); they are not to be called glands or secreting organs, but ought to be classed with the epidermis-cells in point of function. A bladder filled with water, which passes through its walls and evaporates from the surface, cannot be called an organ of secretion.

In many kinds of hairs, however, we must admit that a true secretion takes place. Of some the heads or extremities are filled with ethereal oils, which are transpired through the walls, and are attached to them either in the form of drops or of a resin, produced by oxidation,—as, for instance, in Cuphea selenoïdes.

Besides these simple glands, there are also compound ones, being those which are fixed, by means of little *stalks*, upon two, three, or more cells, developed from each other and joined together. Those fixed upon two cells thus conjoined occur very frequently. They perform the same function as the simple glands, above referred to.

The name of sessile glands, *glandulæ miliares*, is given by Meyen to those organs which are generally indicated by the name of *Stomata*, and exist at the surface of the leaves. According to him, they are small, sessile glands, situated in the apertures of the epidermis, which they close. They consist of two cells, of a half-moon shape, having their concave sides directed towards each other. Thus they have an oval appearance, and are as such enclosed between the cells of the epidermis. These two cells leave between them a roundish cleft-like opening, which has given rise to their name of stomata. These slits or clefts are sometimes closed, sometimes open; often the appearance is different in the same plant each time that they are examined. Their opening and closing, therefore, does not seem to depend upon general causes, but upon circumstances of which we know nothing.

According to Link, these two organs, placed on either side of the cleft, serve chiefly for the evaporation of water. If this be the case, they also ought not to be called organs of secretion, and are not really different from any cell that is placed at the surface of parts filled with liquid. Sometimes, however, these little organs are actually covered with a peculiar substance, and in these cases their function is unquestionably one of secretion. In some species of aloe, for instance, the entire opening is sometimes filled with resin (Meyen*).

* On the Stomates may be consulted the Dissertation of Krocker: De Plantarum Epidermide. Vratislaviæ 1833.

These stomata are very different in different plants. In cellular plants they occur very rarely, but they exist in most of the vascular plants. They are present in all the mono- and di-cotyledonous plants, except in those that live under water. They are found chiefly in the leaves, often in the stem, but never in the root. They occur most abundantly on the under surface of the leaves; in some plants they exist on both surfaces, but very seldom on the upper surface alone (Rudolphi)*. Through them the air cavities (*cavitates respiratoriæ*) communicate with the atmosphere.

Those organs which are commonly distinguished by the name of organs of secretion belong, without doubt, to the class of compound glands. They consist of an agglomeration of cells, are either sessile or stipate, and sometimes both kinds occur on the same plant. They either protrude beyond the surface or remain concealed below it. Instances of the former kind may be found on the under surface of the leaves of Humulus lupulus; of the latter in those of Dictamnus albus. Sometimes they are hollow internally, and are then filled with a peculiar fluid;—for instance, with an ethereal oil. Sometimes they differ in different parts of the same plant, as in Dictamnus albus. This may in several cases account for a difference in the ethereal oil secreted by them. When a plant, on being subjected to distillation, yields a mixture of different oils,—which frequently happens,—this may perhaps be caused by a difference in the glands on different parts of the same plant. The walls of the cells of these glands are sometimes so thick that the oil cannot evaporate through them, unless the walls are forcibly rent. They may also be covered with epidermic cells, and thus evaporation be impeded.

There is another kind of organs belonging to this same class, viz., those which are known to contain acrid and inflammatory substances, which they discharge as soon as they are touched. Such organs are found, for instance, in the nettles, Urtica urens, and U. dioica. A mass of cells protrudes from the surface. This mass passes into a conical hair, which

* Anatomie der Pflanzen, Berlin, 1807. P. 74.

is probably the true organ by which this acrid substance secreted. According to Meyen, the hairs of Urtica nivea nettle which does not emit any inflammatory substance, united with the underlying cellular mass in an entirely di rent manner, and this species is devoid of a certain pecul layer of cells in the bulb of the hair, which is present in stinging nettles. In this hair the stinging substance is ac mulated, which it gives out on being broken by the tou The smaller hairs of Urtica urens, when touched by the sk cause far less stinging, and consequently the liquid they c tain is either of a different nature or more diluted than former.

Besides the organs of secretion already mentioned, pla contain several others of various structure; but those h treated of may suffice for our purpose. What we have s ed before regarding the manner in which the internal gla produce their peculiar substances, is also applicable to the ternal glands.

Among the secreting organs of plants, the *nectaries* are v remarkable. It is a fact of peculiar interest, that on th parts of flowers in which a saccharine matter is secreted, do not always find any special series of cells to effect this cretion. In those cases this substance transpires through walls of underlying cells, in the same manner as happens the bractæ of buds, for there also the resinous substa which they yield is not produced by peculiar organs, exudes through the walls of the cells. These instances sh most clearly, that a change takes place within the *cont of the cell* itself, the new product being simply transmitt and that the walls of the cells have no influence upon secretion.

The true nectaries consist, according to Meyen, of noth but cells; and in Mirbel's opinion, the spiral vessels are h without any influence. They are frequently situated at foot of the flower, are sometimes of very large size, and g out the secreted substances through the walls of the exte cells. The appearance of the cells of these organs is so times different from that of the other cells, being, for insta

very small in Fritillaria imperialis; in most cases, however, no difference can be perceived. The sugar they contain is grape sugar. It is sometimes found crystallised in the nectaries, but it is mixed with other substances, such as resins, wax, ethereal oils, poisonous matter, &c. The honey which bees collect from plants containing those last named, may thus become poisonous too. The secretion of the nectar is connected with the time of flowering.

In a great many plants, we find on the surface transpired substances, without any perceptible organ being present by which these substances have been produced. They merely pass by transpiration through the walls of the exterior cells, and may be very different in different plants or parts of plants. On a great many fruits, such as grapes and plums, we perceive a kind of dew or waxy covering. We find this in great quantity on the fruits of Musa paradisiaca, on the leaves of the various kinds of Mesembryanthemum, and especially on the fruit of Myrica cerifera. This dew is wax.

On the surface of a great number of Algæ and Conferves a mucilaginous substance collects, which Mohl* classes with those substances that, according to him, are found between the cells of many phanerogams. He calls this inter-cellular matter, but Meyen considers it a secretion, intended to protect fresh water conferves against the action of the water, as a great number of fishes are protected by a mucous envelope.

The rule formerly mentioned applies to all these secreting organs, viz., that it is not through their walls, but by their form, position, &c., that they withdraw parts of the surrounding saps from the *general* causes of change, exposing them to *special* agencies. The contents of a small group of very small or very large cells, of one placed close to or far from the surface, must necessarily be different from the *general* contents of the cells in the plant.

We must regret that we cannot as yet give any further

* Erlauterongen meiner Ansicht von der Structur der Pflanzensubstanz. Tubangen, 1836.

information on this point. We cann
ple explain the particular functions of
But this we may consider as establis
these organs of secretion are formed
plants, by their being withdrawn fro
change of materials, and then underg
themselves, of which in most cases p
are the results.

I. On the Gases found

In plants we find many parts th
It would, however, be incorrect to co
organs, serving for the reception of ga
ple reason, that any space in plants
watery liquid must necessarily be fill
and consequently no really empty pl
It would, therefore, be a far too gener
sidered those organs in plants whi
peculiarly intended for that function.

It is well known, for instance, th
or branches is originally very juicy,
completely filled with air, simply be
cells has been used up, and the c
empty, are filled again from the surro
The same is the case with the cells
leaves, whilst the hairs, which are pro
from the beginning void of sap and f

It is difficult to acquire certain
organs in plants serve for the secr
difficult to determine the nature of
in these cavities.

Plants contain two different kind
gases, viz., *air-cavities* and *air-cana*
from the destruction of the cellular ti

* Meyen, Ueber die Secretions-Organe de

disjunction of rows of cells. The former occur very generally, and are formed as the plants increase in age. They frequently pass through entire parts of plants, and are not in direct communication with the external air, but on the contrary, almost always secluded from it. Consequently, they do not take part in that function of plants which consists in the secretion of air, and may be considered entirely passive under the influence of the atmosphere. Such passive air-containing organs are also the vesicular air-bags that are found in Sargassum Columbi, Fucus vesiculosus, and other plants. These cavities must not be confounded with the real air-canals; and from the air in these cavities we cannot draw any inference as to the nature of the gases contained in the latter.

The following experiments have been made with air from air-cavities.

Calvert and Ferrand (Annal. de Chim. et de Phys. Aout. 1844, p. 477, and Journ. de Pharm. et de Chim., Juin 1844, p. 433) have examined the gases that are found in plants, marking at the same time the different organs from which these gases were collected. They have justly rejected such experiments as were made with parts separated from the parent plant, and placed under bell-jars; because in this manner violence is done to the nature of the plant, and from the results thus obtained no conclusions can be drawn as to what actually takes place in the living plant. They, with equal justice, pronounce the same opinion upon experiments that have been made with entire plants under bell-jars, because the air in the jar is soon saturated with watery vapour, by which the perspiration of the plant becomes utterly impossible, and thus a disturbance may take place in other functions. A similar failure may be expected when plants are enclosed under bell-jars with too great a quantity of carbonic acid or oxygen. In a word, it is necessary to study the functions of plants and animals by means of observations, and to abstain as much as possible from experiment.

Since the correctness of this opinion cannot be denied, a great many experiments, upon the inspiration and expira-

tion, the evaporation, &c., of plants, on which; till rec
many theories in vegetable physiology had been estabi
must fall to the ground. The experiments, therefo
Calvert and Ferrand, were exceedingly acceptable.
have investigated the subject in question on the plant i
in its natural condition.

The experiments made by de Saussure had induced
to consider it as a fact, that green parts, when expos
the air, inhaled oxygen, and exhaled carbonic acid, and
versa, in conformity with the alternations of day and n
The oxygen inhaled is converted into carbonic acid, w
is decomposed in some other part, and the oxygen
given off by expiration. But this decomposition ma
either complete or partial, and this is the reason why pl
give off, by respiration, a mixture of oxygen and carb
acid. De Saussure observed in Cactus opuntia an inhala
of oxygen during the night, and an exhalation of oxy
during the day. (Recherches Chimiques sur la Végéta
pp. 66 and 82.)

Bérard, on the contrary, found that fruits, placed u
bell-jars, always gave off carbonic acid, both in the light
in the dark.

These points were first tested by Calvert and Ferr
They first examined the air contained in the legumes
Colutea arborescens. According to Bérard, the pericarp
these pods is completely penetrable to the air, and that c
tained in them consists of the same constituents as atmosp
ric air. Calvert and Ferrand, however, found that this
not the case; that at night the air in the pods containe
maximum of carbonic acid, and that from five o'clock in
afternoon till eleven at night, the quantity of carbonic a
had risen by 1.5 per cent.; that it then continued rising u
the first rays of the sun appeared, which caused a grad
decrease of this gas.

The pods were separated from the plant at the mom
they were to be examined; they were then finely divi
under mercury, and the air contained in them was collec
They had at their disposal pods of different degrees of ma

rity, selected on clear and cloudy days, and made their experiments at seven o'clock in the morning, at twelve, at four in the afternoon, and at eleven at night; the experiments were carried on from the 10th July till the end of September. As these pods require a month to ripen, and this period fell within that of their experiments, they examined them successively at the age of one week, of a fortnight, of three weeks, the latter being fully developed, but still green, and finally after they were transparent, almost dry, and the seeds coloured. The gases collected were dried and measured; the carbonic acid was removed by potash, and the quantity of oxygen determined by a eudiometer with hydrogen. The results were as follow:—

Pods of intermediate age.

Hours.	Time of the day.	Oxygen in 100 measures.	Carbonic acid in 100 measures.	Oxygen and carbonic acid together.
11	night,	20·496	2·746	23·242
7	morning, cloudy,	20·673	2·618	23·291
12	forenoon, do.,	20·908	2·429	23·387
4	afternoon, do.,	20·901	2·432	23·338
7	morning, sunshine,	21·086	1·903	22·989
12	forenoon, do.,	21·293	1·419	22·712
4	afternoon, do.,	21·173	1·438	22·611
		Young pods.		
11	night,	20·583	2·639	23·222
7	morning, cloudy,	20·626	2·605	23·231
12	forenoon, do.,	20·766	2·446	23·212
4	afternoon, do.,	20·743	2·475	23·218
7	morning, sunshine,	20·844	1·934	22·778
12	forenoon, do.,	21·032	1·762	22·794
4	afternoon, do.,	21·246	2·098	23·344
		Old pods.		
11	night,	19·297	2·942	23·239
7	morning, cloudy,	20·166	2·609	22·775
12	forenoon, do.,	20·626	2·461	23·087
4	afternoon, do.,	20·595	2·475	23·070

Old pods.

Hours.	Time of the day.	Oxygen in 100 measures.	Carbonic acid in 100 measures.	Oxygen and carbonic acid together.
7	morning, sunshine,	21·139	2·316	23·455
12	forenoon, do.,	21·246	2·106	23·242
4	afternoon, do.,	20·676	2·107	22·783

It appears from these experiments, 1st, that the air in these pods is much richer in carbonic acid than atmospheric air.

2d. That the quantity of carbonic acid is much greater at night than during the day.

3d. That both the intensity and the duration of the light cause a diminution in the quantity of carbonic acid.

4th. That the decrease in the quantity of carbonic acid, through the influence of light, is closely connected with the power of vegetation.

5th. That the quantity of oxygen increases with the decrease, that is, the decomposition of the carbonic acid, from which it follows that the increase of oxygen may be derived directly from the carbonic acid decomposed.

6th. That the carbonic acid present almost always displaces nitrogen.

These experiments, therefore, have shown that plants decompose carbonic acid, even without the *direct* influence of the sun ; that this decomposition commences with the dawn, and continues throughout the day.

In exactly the same manner they made another set of experiments with parts of plants, in which the air was contained in cavities. Here, also, the experiments were made at the moment that the parts were taken fresh from the young plant

Heracleum sphondylium, No. 1.
Angelica archangelica, No. 2.
Ricinus communis, No. 3.
Dahlia variabilis, No. 4.
Arundo donax, No. 5.
Leicesteria formosa, No. 6.
Sonchus vulgaris, No. 7.

	Carbonic acid in volume.			Oxygen in volume.		
	At night.	In day time.	Increase at night.	At night.	In day time.	Increase at night.
1.	—	1·408	—	—	19·653	—
2.	1·581	1·766	0·815	20·364	19·784	0·580
3.	3·078	2·721	0·357	18·656	16·876	1·780
4.	3·133	2·881	0·252	18·823	18·119	0·704
5.	4·619	4·407	0·212	18·691	18·193	0·498
6.	2·879	2·267	0·612	19·137	18·703	0·434
7.	—	2·326	—	19·774	17·378	1·803

According to these experiments, the air present in the stalks of the plants is of a peculiar nature, containing a large quantity of carbonic acid, and much less oxygen than atmospheric air. The quantity of carbonic acid is larger at night than during the day, but the difference is smaller than in the pods. The quantity of oxygen also increases at night, which is contrary to what was found in the pods.

Calvert and Ferrand have further examined the air within plants for free ammonia, which they have actually discovered. They determined it quantitatively by chloride of platinum, throwing it down as platino-chloride of ammonium. Leicesterea formosa, Arundo donax, Ricinus communis, Phytollacca decandra, and pods of Colutea arborescens, all yielded more ammonia in the day than at night. From quantities of 1170 cub. cent., for instance, they obtained 10 milligr. of the platinum salt. I shall not, however, quote these results, because, from the nature of the experiments, they cannot possibly have been correct.

The kinds of air here mentioned are, therefore, different from atmospheric air. As to the origin of this gaseous mixture, it follows most clearly from the above experiments, that it has simply been derived from atmospheric air, which either entered into the plant along with the water from the soil, or passed through parts of the plant, previously filled with sap which had been lost by evaporation. This air, entering into the empty space, has probably filled the empty medullary cells or cavities. The small quantity of carbonic acid

present in the latter,—though greater than the proportion contained in the atmospheric air,—is to be traced to the carbonic acid, which exists in the saps of all plants.

It requires no argument to show that this air, confined in cavities, has nothing to do with the separation of oxygen or nitrogen, or the absorption of carbonic acid by plants.

Entirely different are the air-channels or passages, which are regular in form, and appear to belong to the active air-holders. Formerly the spiral vessels were considered as the true air-channels of plants, and it was even thought, that a direct communication had been found between these and the stomata. It has appeared, however, that the spiral vessels, although containing air, sometime after their formation, are not the parts which establish a direct communication between the interior of the plant and the atmosphere. The active air-channels are columnar, often sharp-edged, and contain partitions at certain distances, which, like the walls, are composed of cells. Sometimes these channels are very long and without partitions; and they are separated from each other by one, or sometimes by several rows of cells.

These air-channels communicate with the atmosphere by means of the stomata. The cells of the epidermis, and especially the cuticle, impede the connection of the saps with the atmosphere. Diffusion of gases must take place through porous bodies, which may be either dry or moist; it is effected very powerfully through a layer of gypsum, or some animal membrane. But this diffusion is very much impeded by the cuticle, owing to its being penetrated with wax.

But whilst the atmospheric air enters through the stomata and spreads through the air-channels, it is only separated from the contents of the cells adjoining these channels by thin membranes of cellulose, and thus ample opportunity is afforded for a diffusion of gases. The separation of oxygen and nitrogen is caused by a change of materials in the contents of the cells, and not by organs or cellular walls. This change of materials occurs in many parts of the plant, and both the secreted gases and the absorbed carbonic acid, which is also decomposed in several parts of the plant, must

therefore, frequently travel a long way, either in the form of gas, or dissolved in the watery sap, before they reach the spot where the carbonic acid is decomposed, and the other gases can be discharged into the atmosphere. In the air-channels mentioned above, the gases are exchanged according to the laws of diffusion. In one place, nitrogen when liberated is exchanged for carbonic acid; in another, the latter gas exchanges with oxygen; and whilst, therefore, carbonic acid enters, the final result is the emission of oxygen and nitrogen from the plant.

K. On the Absorption of Carbonic Acid, and the Emission of Gases by Plants.

The connection of plants with the atmosphere is as important as their connection with the soil. It would appear that they derive the largest quantity of their materials from the atmosphere, but that their most important constituents are derived from the soil.

A respiration has been ascribed to plants, like that which takes place in animals. In the absence of lungs there can be no *breath*, and no *breathing* or respiration, therefore, can take place.

But it is certain, that plants take much from, and yield much to, the air. They chiefly yield oxygen, and absorb carbonic acid. These phenomena, to which so many philosophers have directed their attention, have special claims upon our consideration. They are not directly related to each other. The absorption of carbonic acid takes place according to the law of the diffusion of gases; whilst the excretion of oxygen is the result of a chemical change of the constituents, which is characterised by the production of solid or liquid substances, containing little oxygen.

Of the secretion of oxygen we have treated before in the chapter on the conversion of vegetable substances; but we will here say something about its excretion. It comes out through the stomata, and it is therefore derived from substances in the contents of the cells, placed beneath the

surface. The epidermis contributes nothing to this excretion, for Senebier found that leaves, from which the epidermis had been removed, yielded as much oxygen as others with the epidermis. Consequently, the stomata are only the places through which the liberated oxygen is emitted. When they are not present, this gas may escape through the entire surface of the part. But its excretion is prevented by a cuticle thickened with wax.

The idea that the excretion of the oxygen depends on the surface, and not on the mass of the leaves (de Saussure, Rech. p. 57), has tended very much to perplex our conceptions regarding the real character of this excretion. There is no relation between the surface of a plant and the amount of oxygen liberated.

This liberation depends on the number of molecules which are in a state of de-oxidation, and, therefore, it is in direct ratio to the mass of the leaves. But the light, whilst shining upon the surface, does not penetrate deep through the surface of fleshy leaves, and hence the excretion of oxygen depends on the influence of the light, inasmuch as light is a chief requisite for the production of those substances in plants which contain little oxygen.

The excretion of oxygen, therefore, is regulated more by the surface, than by the mass of the leaves—not because the surface contains active and secreting organs, working in some mysterious manner—but because the influence of light, in producing these molecular changes, acts in proportion to the extent of surface. If it were possible, for instance, to arrange in one plane, all the layers of cells of a leaf, in which fifty such layers are packed upon one another,—in which way the surface of the leaf would become fifty times greater—then the substances contained in these membranaceous bags, would probably have reached their maximum of oxygen in a fiftieth part of the usual time, and in the same period, have yielded their maximum of oxygen.

Some of the substances that are present in plants possess not only a tendency to lose oxygen, but also the power of transferring that tendency to other substances, even to the

carbonic acid which is introduced into the air-channels through the stomata. This carbonic acid, of which the constituents are firmly united together, is, under these influences, either decomposed by itself, or its component parts combine at the same time with other substances in the cells. This subject has been considered before. It may suffice here to point out the entire want of connection between the absorption of carbonic acid and the excretion of oxygen, except in so far that the decomposition of carbonic acid and the separation of oxygen from it gives successively a new opportunity to absorb more carbonic acid.

All experiments made to prove the absorption of carbonic acid and its decomposition in plants, must always labour under the following difficulties.

Every conversion of oxygenised into de-oxidised substances, which is regularly going on in healthy plants,—for instance that of starch into B. chlorophyle (p. 289).—is attended by a disengagement of oxygen.

This excretion, which is in some respect independent of the gases with which the plant is surrounded, must cause an increase of the quantity of oxygen in the atmosphere in which the experiment is performed, and thus the accuracy of the observation must be considerably affected.

When the artificial atmosphere contains a large quantity of carbonic acid, this will rapidly saturate all the saps and moist parts of the plant, before the plant itself has any active share in this phenomenon. Every cubic inch of sap absorbs about a cubic inch of carbonic acid, simply because the sap is a watery liquid. The decrease in the quantity of carbonic acid, therefore, may also be owing to other causes besides the decomposition effected by the plant.

Finally, when the plant contains oxidisable substances,—for instance, ethereal oils, which can be converted into resins,—this is a source of diminution in the quantity of the surrounding or disengaged oxygen. This must give rise to new errors in the determination of the carbonic acid absorbed and the oxygen given off.

The reason why I bring the difficulties attending experi-

ments of this kind so prominently forward, is that we may be able not only to account for the uncertain opinions given by former observers upon this well known phenomenon, but also to understand the cause of the discrepancies which must always attend those experiments, when made with different plants and under different circumstances.

It would be beyond my purpose to enumerate the great number of experiments that have been made to prove the absorption of carbonic acid by the leaves. They are all mentioned by Van Rees, (Comment. de decompositione Acidi carbonici in Vegetatione. Traj. ad Rhenum, 1818,)—by Meyen, Phys., II. p. 144, and also by other writers. This function has been firmly established by de Saussure, Grischoud, and others. And yet these observers themselves, and others, even till very recently, have published so many singular facts upon this subject, and so manifestly overlooked the errors to which their observations are liable, that our knowledge on this point, although very extensive, possesses but little that is useful. I will quote one or two instances.

The experiments made by Schultz and communicated in a letter to Flourens (Journ. de Pharm. et de Chemie, Oct. 1844, p. 299), which are intended to show that the oxygen which plants give off is the result, not of the decomposition of carbonic acid, but of that of vegetable acids, viz. gallic, malic, lactic, tartaric, and citric acids, appear to prove too much. If it be a fact that plants, when placed in solutions of these acids, yield oxygen in the same ratio in which the quantity of acid in the solution diminishes, this cannot by any means indicate what happens in the natural condition of the plant. And even supposing that a vegetable acid is actually decomposed in the plant, and is the cause of the separation of oxygen,—other substances that remain behind being formed at the same time,—the question still is, from what substances malic and tartaric acids, &c., have been originally produced in the plant.

These experiments of Schultz, therefore, prove nothing against the absorption of carbonic acid, nor against the idea, that carbonic acid is a source of new substances produced in

the plant, which, being decomposed in their turn, must at last give occasion to a disengagement of oxygen. They show, however, what was already known from the history of humus, and has not yet been disproved by a single experiment, viz.: that plants can absorb solutions both of organic and inorganic substances, and that the former having once entered the plant, and being there exposed to the causes of change of materials, will be chemically altered in such a manner, that they may be called food for the plant.*

Hoffmann (Ann. der Chemie und Pharmacie, Februar 1845. S. 242) has published some experiments on the disengagement of carbonic acid by various plants. He placed them recently cut in a current of dry air free from carbonic acid, dried the air given off by the plant, and then passed it through potash. He obtained from 100 grms of the plants, mentioned below, in a moist state, and after 100 minutes, the following quantities of carbonic acid; the experiments were made in the autumn and in daylight.

Agaricus detonsus,	0.272 grms.	
Hypnum repandum,	0.032	
Agaricus puniceus,	0.015	
Russula emetica,	0.032	
Hypnum triquetrum,	0.210	(Green plant, Moss.)
Hypnum tamariscinum,	0.087	do.
Euphorbia peplus,	0.059	Vascular plant.
Urtica urens,	0.048	do.
Cichorium endivia,	0.023	do.

The disengagement of carbonic acid, here referred to, proves nothing as to the natural function of the plant. In a dry current of air, water containing carbonic acid must necessarily evaporate from the plant, and this carbonic acid must be absorbed by the potash. But besides this, it has been proved by Calvert and Ferrand, and also by Draper, that carbonic acid exists in plants in a gaseous state.

In this manner a multitude of experiments has been made on the disengagement of oxygen by plants, which unfortunately are of no value to science.

* The experiments of Schultz have been contradicted by many, who have contrasted them with others.

The following are among those which apparently fulfil this purpose.

Draper, namely, has instituted important experiments on the influence of light upon the decomposition of carbonic acid by plants (Annales de Chimie et de Physique, Juin 1844, p. 214). He has examined, in the first place, how far the experiments of de Saussure and Daubeny were correct, who found that the oxygen given off by plants was mixed with nitrogen; and in the second place, if this disengagement is really an effect of the light of the sun.

The results obtained by Draper, may serve, first, to show the influence of rays of different colours on the phenomenon in question. They are of great importance to our knowledge of the nature of light, because we learn from them that the leaves of plants disengage the greatest quantity of gas when they are under the influence of the yellow and green rays, and more particularly of the luminous, not of the tithonic or calorific rays. But passing over these results, it is more important for our present purpose to consider what he has stated of the disengagement itself.

He placed plants in water free from atmospheric air, but containing carbonic acid, and thus exposed them to the sun. Previous to this he had kept the plants themselves in another portion of water with carbonic acid, in order that all the air enclosed in them might first be absorbed by the water. He thus collected, together with more or less carbonic acid which he found mixed with the disengaged gas, the following quantities of

	Oxygen and Nitrogen.	
Pinus tæda,	16.16	8.34
" "	27.16	13.84
" "	22.23	21.67
Poa annua,	90.00	10.00
" "	77.90	22.10

In every instance, therefore, nitrogen was produced along with the oxygen, and a certain relation seems to exist between the quantities of these two gases. The substance which he employed for the production of coloured light, for

instance, bi chromate of potash, had no influence either upon the quantities of the gases, or upon the ratio between the two.

These two experiments, therefore, have confirmed the conclusion, which was long ago adopted in science on the faith of a number of old experiments, viz.: that the leaves decompose carbonic acid and give off oxygen. It is worthy of special remark, that the oxygen was mixed with so large a quantity of nitrogen. If the latter be always as great, it would tend completely to annul the doctrine, that plants decompose *carbonic acid alone*. For from what else could this large quantity of nitrogen have been derived, than from nitrogenous substances, simultaneously decomposed? If this nitrogen had come from atmospheric air, in consequence of Draper not having freed the water he used from air, the result would be totally incomprehensible; for in this case for every 21 parts of oxygen 79 of nitrogen ought to have been produced, setting aside the oxygen originating from the decomposition of the carbonic acid.

The truth of this result, viz., that along with carbonic acid nitrogenous substances are also decomposed, appears most clearly from other experiments of Draper, made on the decomposition of carbonates.

He dissolved alkaline carbonates—both neutral and bi-carbonates—in water free from atmospheric air, and after having placed leaves in this solution, he observed that oxygen and nitrogen were expelled, and consequently that the carbonates were decomposed. In pure water no gas at all was disengaged.

When placed in the dark, the solutions of carbonates produced no gas, any more than water containing carbonic acid. But when the leaves in the saline solutions were exposed to the light, the disengagement of gas immediately commenced, and the gas evolved contained a large quantity of oxygen. He could not perceive any difference between the quantities of gas disengaged from a neutral carbonate and a bi-carbonate, which had been boiled and thus converted into a sesqui-carbonate. Whenever, therefore, carbonates are present in

plants and enter into the leaves, we may expect their decomposition in the same manner as that of the carbonic acid which is dissolved in the sap—having along with the rain-water penetrated into the roots. But if the acid of a carbonate is decomposed, a quantity of base must be set free, which may then unite with other substances; for example, either with acids newly produced, or with the so-called neutral substances, such as dextrin, cellulose, &c.

The same results were obtained by means of sesqui-carbonate of ammonia. The gas evolved contained 90 per cent of oxygen. The ammonia, therefore, is not here decomposed, but is either fixed or employed for other purposes.

The influence, therefore, which the light of the sun, both indirect and direct, exercises upon the parts of a plant, consists in the decomposition of a nitrogenous body and of carbonic acid, the latter both when in a free state and when in combination with bases. A large quantity of a nitrogenous body, therefore, is employed in the plant for this purpose; and thus Draper has led us to regard in a new light the service of the nitrogenous vegetable substances, which are, in our time, too exclusively considered as chiefly intended for the nourishment of animals. We must, therefore, distinguish two actions which take place in the interior of plants, in reference to this nitrogenous body, viz., its production and decomposition. The latter is effected by the light, the former in the dark, in those parts which are withdrawn from the light. We have seen already, that there are grounds for considering the radical fibres as the place where it is produced.

But, in the second place, we may conclude from the decomposing action exercised by the light on the carbonic acid in the leaves, and from its not being decomposed in the dark, that in the roots and stem, and indeed wherever the light has no access, no carbonic acid is decomposed, or at least not with the liberation of oxygen. Hence the reason, why the leaves and other green parts acquire a large quantity of wax in B. chlorophyle, and why in seeds fats are produced, &c., whilst in the roots, the stem, and other parts inaccessible to light, these substances cannot be found, and therefore are

either wanting or exist but sparingly, and the latter only in consequence of the diffusion of the sap.

In a physiologico-chemical point of view, it now becomes a matter of still more importance to investigate what products are found in plants that grow in the dark; what substances remain absent, and what are produced instead of those that are found under the influence of light. Draper further states that plants, and especially the spiral vessels, contain air, in which from 88 to 94 per cent. of nitrogen is found. The nitrogen obtained in the above-mentioned experiment on the disengagement of gases, must not be ascribed to this source, for the leaves, which were subjected to the experiment and placed in the solution of alkaline carbonate, had first been placed *in vacuo*, and been thus deprived of the whole of the air, and consequently also of the nitrogen, they contained; and yet, when exposed to the light, they again yielded a mixture of oxygen and nitrogen, containing, it is true, a little less nitrogen than before—as might be expected,—but not so much less as would annul the conclusion that a peculiar nitrogenous body is decomposed in the leaves.

It is probable that the nitrogen in the spiral vessels has no other source than the atmospheric air dissolved by the saps in the roots, and thus introduced into the plant. The oxygen of this air must be employed for the oxidation of various substances; and the nitrogen, remaining in a free state, passes through the existing cavities, such as spiral vessels and intercellular canals, and is at last expelled at the surface of the leaves.

Draper found that the quantity of gas disengaged by the influence of light, was always exactly equal to that of the carbonic acid absorbed. In one experiment he had employed 20 measures of carbonic acid, and obtained 20 measures of a mixture of oxygen and nitrogen. This agrees with the result of an experiment of de Saussure (*Recherches Chim.*). The latter placed seven shoots of Vinca pervinca in a bell jar, which was isolated from the air by means of mercury, while the mercury

again was covered with a little water, to prevent its ev
tion. The bell jar contained—

	Before the experiment.	After seven days.
Nitrogen	4199 Cub.-Centim.	4338 Cub.-Cen
Oxygen	1116 —	1408
Carbonic acid	431	0
	5746	5746

The conclusion drawn from this result is, that not o
whole of the carbonic acid had been absorbed, but that
been replaced by oxygen and nitrogen, in the propo
292 c.c. of oxygen and 139 c.c. of nitrogen, together 4
that is, exactly equal to the quantity of carbonic acid
the experiment.

But this simplicity of relation is, in my opinion, acc
The carbonic acid is employed for the production of
organic bodies, which cannot possibly be the same
plants. Consequently, the quantity of oxygen given
not be a constant one. This variety of products also
it impossible that a constant amount of a nitrogeno
stance should be required for the decomposition of
bonic acid. Draper himself found, that towards the
the experiment more nitrogen is disengaged than at the
ning, which cannot be otherwise accounted for than by
ing that the nitrogenous body, which yields the nitr
first separated into various intermediate compound
whilst this is going on it promotes or causes the dec
tion of the carbonic acid ; and that its own final decom
and the liberation of nitrogen only takes place in the
of the action. It appears from this that, in every ca
relation between the quantity of nitrogen and that of
is only accidental.

It is necessary that we attempt a more special expl
of the important phenomenon now under considerati
is certain that carbonic acid is absorbed by the gree
of plants, which again evolve oxygen and nitrogen. I
is not sufficient to make us understand the phenc
Draper's experiments show that nitrogenous substances
the plants are decomposed into their elements. What els

be the source of the nitrogen that is given off by plants? If this nitrogen is derived from vegetable albumen, the latter ceases to be albumen, and whilst being thus changed, it may give rise to the production of C. chlorophyle (p. 290), vegetable alkalies, and other nitrogenous substances, containing less nitrogen than albumen. The molecules of albumen, therefore, whilst in a state of transformation, supply this nitrogen, and are themselves converted into new compounds. This change occurs at the places where these new bodies are found, that is, in the cellular contents, where these bodies are to be deposited. In the same place, therefore, the nitrogen is set free. It is inclosed, dissolved in the sap of the cells, until it can be exchanged by gaseous diffusion. Water can take up an appreciable quantity both of nitrogen and oxygen (p. 129) Whilst the cells mutually exchange their saps, they carry this nitrogen along. It is subsequently conveyed into the air canals, in which it is, by diffusion, exchanged for carbonic acid, and thus may be discharged through the stomata into the atmosphere.

This nitrogen, therefore, is a final product of the change of materials in plants, as carbonic acid is in animals; or, if we wish a still more striking comparison, nitrogen is a final product of the decomposition of protein in plants, as urea (*anomalous* Cyanate of ammonia) is from the same substance in animals.

The oxygen, disengaged by plants, must originate from a totally different class of bodies. We do not know what these are, with the exception of carbonic acid. But it is certain that the oxygen is a product of the change of materials among substances existing in the plant. We know some of these, — for instance, starch, concerning which we may consider it as established, that it is occasionally converted into fat, a change which is attended by a loss of oxygen (p. 263). Starch is formed from dextrin, the latter again from substances with which we are not acquainted. Suffice it to say that wherever substances containing little or no oxygen, such as starch, real oils, and fats, are formed from others rich in oxygen, such as sugar, oxygen must be given off.

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which it is expelled through the
into the atmosphere.

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effected, the oxygen and nitrogen of the plant are diffused through the atmospheric air inclosed in the air-canal, and in the same manner the carbonic acid of the external air is continually diffused, entering into and below the stoma. It is as if we had a narrow tube, with carbonic acid at the top, oxygen and nitrogen at the bottom, and a mixture of 79 per cent. of nitrogen and 21 of oxygen in the middle.

Perhaps it may be argued against this, that we do actually perceive a more energetic action proceeding from the plant; for example in the expulsion of oxygen, when we expose green parts lying in carbonated water or in a weak solution of carbonates to the influence of the sun. But this separation is not more active than it ought to be, according to the laws of gaseous diffusion. The exchange of the two gases, carbonic acid and oxygen, takes place in a thin and moist membrane. The carbonic acid enters into the sap, the oxygen leaves it. The latter is much less soluble in water than the former, and therefore it must, for the greater part, appear in the gaseous form in the water which covers the plant. Every cause of expulsion of an ordinary mechanical nature is here entirely superfluous. The phenomenon is sufficiently explained by the exchange between carbonic acid and oxygen from the great solubility of the former, and the small solubility of the latter. Hydrogen is so energetically diffused through a layer of gypsum when exchanging with atmospheric air, that when the experiment is made in the pneumatic trough, a considerable column of water is raised above the level. According to Graham, carbonic acid, nitrogen, and oxygen, require an equal period of time to penetrate through a layer of gypsum.

It is worthy of special remark that the air-canals in plants, which are in communication with the external air through the stomata, do not penetrate deeply into the tissue, but must really be called shallow. Any change, therefore, in the atmosphere in these canals ought to be characterised by peculiar productions, if the above mentioned diffusion of gases through the saps in the cells, and their gradual production and decomposition, did not take place in the manner I have here described. But the contents of the cells adjoining the

air-canals present nothing particular, and, therefore, the formation of new substances from the carbonic acid and the liberation of oxygen and nitrogen is not confined to this spot, but goes on throughout the whole tissue that is affected by the light. Hence the reason why part of the absorbed carbonic acid may again be driven out from those organs which contain cellular sap impregnated with carbonic acid, and supplied from other parts, but which are incapable of fixing the carbonic acid into new combinations, because their contents are unfit for this purpose.

We learn from the experiments of Calvert and Fernal (p. 765), that the gases which are inclosed in the large cavities of plants contain a certain amount of carbonic acid. This carbonic acid is derived either from the rain-water in the soil or from the atmosphere; it is held in solution by the cellular saps, and is mixed with the other gases with which these cavities are filled; it is separated from the sap contained in the cells which adjoin these cavities. This, therefore, is a direct proof that the carbonic acid first becomes a gaseous and dissolved ingredient of the saps, and that the new products into which it is converted,—though it is not even always so,—are formed at a later period and in a different place.

And so we are led, as it were involuntarily, to the well-known phenomenon, that plants when in the dark also excrete carbonic acid. This carbonic acid was dissolved in the saps. The action of light, by which chlorine and hydrogen are suddenly combined into hydrochloric acid, and which produces such manifold chemical actions in plants, assists the conversion of oxygenised bodies into others containing little or no oxygen. This conversion is a chief condition for the absorption of carbonic acid from the air in the air-canals, for this absorption can only be effected by the exchange of one gas with another. Light is the cause of the production in the leaves of such substances as are poor in oxygen; light causes the disengagement of oxygen from the leaves; light, therefore, is the cause of the exchange of carbonic acid with oxygen, and consequently of the absorption of carbonic acid by plants.

But in the dark there is no sudden combination between

chlorine and hydrogen. In the dark the constituents of the cellular sap of the leaves have no tendency continually to produce new and de-oxidised substances; and consequently in the dark no oxygen is liberated from the constituents of the saps adjoining the air-canals. It is plain that in this case no oxygen can be exchanged for the carbonic acid of the canals. On the contrary, the substances in the leaves now follow the usual course of chemical substances; that is, they are oxidised, and, using up the oxygen that still remains in the saps, they render these poor in oxygen. The carbonic acid taken up before and not exchanged, being still dissolved in the sap, is now in a position to diffuse against a mixture of 79 per cent. of nitrogen, 21 per cent of oxygen, and $\frac{1}{2500}$ of carbonic acid (the atmosphere). It exchanges by diffusion with the constituents of the air; as these enter into the sap, the carbonic acid leaves it, and is discharged into the atmosphere.

This phenomenon, which plants exhibit during the night, and which is the reverse of what they manifest in the day time, shows the powerful influence of light upon the chemical actions of the constituents of plants, which have not yet at all been studied in reference to this point. The occurrences, however, that take place in the dark must be of small extent when compared with those that happen in the day-time. At night no more carbonic acid can be exchanged for atmospheric air than what was left unused and near the air-canals, and plants are therefore continually gaining in carbonic acid, at least in long days. When the days are short the loss during the night may be equal to what was gained during the day; and when the obscurity is artificially protracted, the quantity of oxygen absorbed becomes gradually so large that the green chlorophyle is oxidised and becomes colourless (p. 270), that is, chlorosis ensues.

This interchange of atmospheric air absorbed and carbonic acid expelled, which takes place during the night, may be partly the cause of the separation of the nitrogen which plants yield, of which the quantity, however, has not yet been determined by experiment. Yet it deserves a special investigation, which might easily be performed.

It is evident from what has been stated that plants, when kept, for instance, in nitrogen, must yield both carbonic acid and oxygen; that when oxygen is used they must yield carbonic acid and nitrogen, and, finally, when the experiment is made with pure carbonic acid, they must yield nitrogen and oxygen. All this is plain from a knowledge of the simple physical phenomena of diffusion.

The quantity of oxygen and nitrogen which plants give off by a normal decomposition of carbonic acid will depend partly on the diffusing power of the gases, and partly also on a number of other circumstances. I shall only refer to one of these, viz., the nature of the substances of which the plant consists. Every other thing being equal, a Sago-palm tree will disengage much more oxygen than a sorrel (*Oxalis*), although the quantities of carbonic acid absorbed are the same. For while in the latter two equivalents of carbonic acid, on being converted into one equiv. of oxalic acid, can only give off one equiv. of oxygen—every other thing being equal, I say,—the sorrel will not be able to disengage so much oxygen by far as the Sago-palm tree, in which from 12 equiv. of carbonic acid and 10 equiv. of water, one equiv. of starch, $C^{12} H^{10} O^{10}$ is produced, whilst 24 equiv. of oxygen are disengaged into the atmosphere. In the first case, 12 equiv. of carbonic acid eliminate only 6, and in the last 24 equiv. of oxygen.

This illustration may suffice to show that it was nothing else than defective experimenting which gave rise to the assertion, that plants return a quantity of oxygen nearly equal to that of the carbonic acid they have decomposed. Such a uniformity in the products from the food of plants has no existence, and therefore the rule is not true. If we add to this diversity of the substances in plants, a diversity in the growth, in the production of resin, in the relative quantities of the four organic elements, and, consequently, also of oxygen,—then it appears very evident that the law adverted to in reference to this subject only proves how inadequate science yet is to explain the operations of nature.

From what I have mentioned, it will be sufficiently evident that the phenomenon in plants now under consideration

may be compared to the respiration of insects, which do not in reality *draw* their breath; but in their trachea an exchange takes place between the carbonic acid leaving, and the oxygen entering into, the nutritive liquid. And if we choose to compare the present function of plants with the respiration of animals of the highest order, the comparison still holds good, provided the idea of *drawing* breath be abandoned. (See *Respiration of Animals.*)

Water-plants perform the function here mentioned—which ought to be distinguished by a peculiar name—in the same manner as fishes their so-styled respiration. These plants, being devoid of stomata, afford ample opportunity to the carbonic acid, held in solution by the water, to exchange through the exterior layer of their cells with the oxygen given off, and their function is in this respect also regulated by the rules just mentioned.

There is this essential difference between the respiration of animals and that of plants, that the latter yield, the former absorb oxygen, whilst the latter absorb and the former yield carbonic acid. Since with carbonic acid carbon is introduced into plants, some have preferred to class the respiration of plants with nutrition. This is certainly less of a play upon words than to call animal life a combustion, because animals absorb oxygen and yield carbonic acid instead; for it is a fact, that the greater part of the substance of plants is derived from carbonic acid.

L. On Evaporation

Evaporation from plants has an important influence upon the change of materials which takes place in their interior. When their parts are filled, or at least soaked with a watery fluid, they will yield much of their moisture to dry, and less to moist, air, according to the well known laws of evaporation. This function of plants is not the effect of a peculiar power. The stem of a tree, a stick, a branch, a wet cloth, or a leaf, all lose part of the water they contain when they are exposed to dry air. This evaporation takes place

in winter as well as in summer, for even ice evaporates and diminishes in quantity by giving off part of its substance to the atmosphere. In summer the water evaporated from living plants is restored from the soil, in proportion as it is present there, and with this restoration the plant is at the same time supplied with the substances that are held in solution by the water, whilst nothing but pure water is given off by them during evaporation. (Chapter VIII.)

The stomata have erroneously been considered as the places from whence the evaporation of water exclusively takes place. It is true that the cuticle and epidermis are of such a nature that they do not favour the evaporation of water from the juicy cells lying beneath them; but the cells of the cuticle and epidermis consist of membranes soaked with water, and whilst these are drying up, they re-absorb water from the adjoining parts. Evaporation, therefore, takes place from *all* the external parts of the plant without exception, because all the external parts are either moist or in communication with moist parts.

The same cause, however, which makes water evaporate from the whole surface of the plant, effects the emission of watery vapours from the stomata, because they are in communication with cavities which are surrounded by sap-holding cells. The quantity of water that is given off from these parts, all other conditions being equal, depends on the evaporating surface, and we have, therefore, to inquire, what the extent of these cavities is. It is no doubt an error to think that the emission of watery vapour should take place chiefly through the stomata.

A larger quantity of water, however, must evaporate through the stomata than through an equal superficial extent of the cuticle, because the latter contains much wax, whilst the cells of the cavities, with which the stomata are in communication, have thin walls not covered with cuticle, and, therefore, not impeded by wax, which counteracts evaporation.

This wax of the cuticle is the cause why fleshy fruits dry up so slowly. They contain such a large quantity of

wax in their cuticle, that their surface often becomes smooth and shining (see p. 268). The slowness of evaporation is in proportion to the thickness of the cuticle.

The evaporation of watery vapour through the stomata is further assisted by their exhalation of oxygen; for this gas will necessarily carry away the watery vapours that are present in the cavities of the stomata, and thus it will be given off as moist oxygen.

But on the other hand, circumstances are unfavourable to the evaporation from the stomata in the dark, when they give off no oxygen, but instead of this a small quantity of carbonic acid; for evaporation can proceed but slowly from an enclosed space, only communicating with the atmosphere through a small opening.

This evaporation, whether effected in the cavities of the stomata or on the surface of the cuticles, or from some other place, depends on the temperature, the hygrometric state of the air, and of the evaporating surface, and also on the quantity of sap in the plant, and on the thickness of the walls of the cells of the cuticle and epidermis. Evaporation in plants is a purely physical phenomenon, which is fully explicable by physical laws.

It has been asserted, on the authority of the experiments of Senncbier and Hales, that not heat but light is the cause of the evaporation of water from plants. These experiments are said to prove, that evaporation diminishes in the shade, and ceases at night, whilst on the contrary, it is at the highest stage during the day and in full light, even when the temperature is low. I am not aware that any experiments have been made, which have shown this result with certainty, and I therefore doubt the correctness of the conclusion. The evaporating water existed in the plant as such, and there was no necessity for its being produced from its elements. Neither is the evaporation of water connected with the transformation of substances in the plant, and it would therefore be very singular, if the evaporation of these humid substances were regulated by the light, whilst that of every other is regulated by heat. The former is true, only in so far

as the giving off of the oxygen—which, as has just been explained, influences the evaporation—depends on the action of light.

M. On the Oxidizing Influence of the Atmosphere upon the Substances produced by Plants.

It is altogether erroneous to suppose that everything which plants contain has been secreted and prepared by them in the form in which we find it; that is, that all this is the direct result of the change of materials within a plant. Every part of the plant, when exposed to the atmosphere, is always affected by its agency, provided it be capable of being so. Every substance that is present in plants, and is capable of absorbing oxygen, or producing new bodies by its influence, is always more or less changed by it, because the air has access to a great part of the interior of the plant.

This influence, therefore, will vary with the degree in which the air can reach the substances that are capable of being changed, and also with the total or partial withdrawal of the action of other substances within the plant, that are capable of modifying the influence of the atmospheric air.

The constituents of the juicy parts of plants are changed but little by the atmosphere, because they abound in a watery liquid containing little air, or none at all. This water protects the substances that are dissolved or diffused in it, or even those that have already been separated in the solid state, against the influence of the atmospheric air. All parts, however, that are less juicy, especially those that are old, in general all that are not saturated with watery liquid, are very much altered by this influence.

Only a part of the five constituents of the atmosphere, water, ammonia, carbonic acid, oxygen, and nitrogen, can exercise here some particular influence. We may safely leave the nitrogen out of account, and likewise the water and carbonic acid, both that which is introduced through the roots, and that which is absorbed by the leaves, as far as they are not connected with nutrition, of which we have already treated before.

All that remains, therefore, is the ammonia and the oxygen. The influence of the ammonia is very limited, as is shown by experience. The lichens, which yield litmus, by the action of ammonia and oxygen, remain colourless in the atmosphere; from which it appears that the small quantity of ammonia which the atmosphere contains, exerts upon them no influence whatever. We may assume the same with regard to other plants, with the single exception, perhaps, of the very delicate colouring substances of some flowers, which, when placed in an atmosphere with ammonia and carbonic acid, actually appear otherwise than they would do, after the removal of these two gases.

Nothing else, therefore, remains to be considered but the oxidising influence of the oxygen, which is unlimited in its effects, and therefore deserves our whole attention. It is the cause of the colouring matter in barks, of the long series of resins, and also of some vegetable acids that are found in plants, and would not exist there if the atmosphere contained no oxygen. If we glance through the various substances of the Vegetable Kingdom, we shall perceive that the atmosphere has an important influence, as it converts substances that were already secreted by plants into new products. (See in reference to this, *The resins, tannic acid, gallic acid, cinnamonic acid, benzoic acid*, &c.)

The chemical composition of the various barks of woody plants is much more uniform than that of the wood of these plants. In the first place, they contain the substances that have been carried down from the leaves. These substances are generally poor in oxygen or contain none at all, because a chemical change of a de-oxidising nature has taken place in the leaves, oxygen having been disengaged from them. It is for this reason, that the ethereal oils, and the resins produced from them (see what will hereafter be said on both), are chiefly found in the parenchyme of the bark.

Hence the general prevalence of the substances with which the barks of dicotyledonous woody plants are filled. These substances do naturally differ from each other, but yet they belong to the same class of chemical bodies.

But there is another reason, why these barks agree so much with one another. The old barks, which have burst by the increasing growth of the wood, and of which the vessels are pressed down, are converted by exposure to the atmosphere into an ulmic substance, which, having a brown colour, gives the same appearance, and even several identical properties, to old barks of very different trees.

Besides this, there occurs a product of decomposition of a constituent, which is common to a great many different barks, viz., the apotheme of tannic acid. This acid is certainly found also in herbaceous plants, in leaves and fruits, but its formation seems to be chiefly confined to the bark.

These are, no doubt, the same substances that are mentioned in the investigation which I am about to quote; for it appears to me, that the Phlobaphen, as it is there called, closely corresponds with the humic substances formerly examined by me (see p. 154). Stähelin and Hofstetter have analysed some kinds of bark (Annalen der Chemie und Pharmacie, Juli 1844, S. 63) and obtained the following results.

From the bark of Pinus sylvestris, they extracted a kind of wax by means of ether. Subsequently, by digestion in alcohol, they obtained substances, one of which was precipitated by water in the form of reddish-brown flocks, whilst the liquid, which had an acid reaction, held another in solution. They called the former Phlobaphen, and found it composed as follows:—

	Found.	Atoms.	Calculated.
C	62·78	20	62·77
H	4·30	8	4·12
O	32.92	8	33·10

It was soluble in ammonia, from which it was thrown down by a lead salt. The liquid, which had an acid reaction, gave a grey precipitate with salts of iron; it was yellow, and had an astringent taste. Its composition could be represented by the formula $C^{20}\ H^{8}\ O^{10}$; but it was a mixture of two substances, one of which was Phlobaphen combined with an equivalent of water.

When the bark, previously treated with ether and alcohol, was digested with alkaline carbonates, it yielded the same substance, and at last nothing remained but the skeleton of the bark, which was composed as follows:—

	Found.	Atoms.	Calculated.
C	52·20	34	52·20
H	5·61	21	5·30
O	42·19	21	42·50

Next to this skeleton the Phlobaphen constitutes the greatest part of the bark, and gives it its brown colour.

A similar substance they found in Platanus acerifolia, represented by the formula $C^{20}\ H^{9}\ O^{8} + 2HO$; whilst the skeleton had the same composition as that from the Pinus.

In China flava again they found a substance $= C^{20}\ H^{8}\ O^{8}$, but, besides this, another represented by the formula $C^{21}\ H^{12}\ O^{7}$.

In Betula alba they obtained again the substance $C^{20}\ H^{8}\ O^{8}$ from the alcoholic solution, and from the alkaline one having the formula $C^{20}\ H^{8}\ O^{8} + HO$.

The temperature, by which these substances were dried, is only mentioned once, viz., 212° F. We rest therefore in uncertainty regarding the composition of these substances.

We may, however, conclude from this investigation, in the first place, that in old barks a substance is present, agreeing with the ulmic bodies in so far that it appears in two different conditions, one soluble in alcohol, and the other in alkalies. This is probably an apotheme. And in the second place, that the entire skeleton of old barks, after being treated with the above-mentioned solvents, appears to be nearly of a uniform composition.

N. On the Ripening of Fruits

In the ripening of fleshy fruits we must distinguish two operations, viz., that of growth and development, and the ripening itself. A great many investigations have been made on this subject, but only a few of them have any value, because this distinction has not been sufficiently kept in view.

Whilst, therefore, I pass over
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T. 46, p. 147). Although Berard
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After the fruit has attained its full size, the stalk dries up and may be easily severed from the plant, whilst at the same time wax is produced in the cuticle, and thus the drying up of the fruit is prevented. From this time both the supply of matter through the stalk and the absorption of carbonic acid from the air are stopped. The fruit has now become an isolated whole, capable of undergoing a change of materials within itself, but only in so far as its materials will reach.

The latter conclusion is chiefly derived from the observations of Couverchel. He observed that fleshy fruits, when fully developed, ripened both on and off the plant.

In his experiments with full-grown and ripening fruits, both on and off the plant, Couverchel always perceived a disengagement of carbonic acid, without any decrease in the oxygen of the air. The question is, whence does this arise? We cannot expect here a separation of carbonic acid, as an effect of chemical reaction, but only one similar to that by which this gas is disengaged from the leaves. I refer, on this subject, to Draper's experiments, and to what I have stated at p. 774.

Couverchel has also made experiments upon the preservation of fruits, both *in vacuo* and in nitrogen—which methods, according to Berard, are well fitted for this purpose. He observed, however, that the chemical transformation of the constituents of the fruits went on constantly, exactly as happens in the air, and he comes to the conclusion, that the taste of fruits cannot under any circumstance be preserved. I can state in addition, that apples, sent from Holland to India, packed in vessels free of air, became perfectly tasteless, although not a trace of putrefaction could be perceived.

Fleshy fruits, and also the several kinds of berries, acquire, while ripening, a much greater proportion of sugar than they contained before maturity, although full grown. Whence, it may be asked, was this sugar derived? Can its presence be traced to substances that are present in the unripe and full grown fruits, and if so, what are these substances? Let us, with reference to this question, consult the analyses of Berard:—

Constituents.	Apricots.		Plums.		Cherries.		Peaches.			Pears	
	Unripe.	Ripe.	Unripe.	Ripe.	Unripe.	Ripe.	Unripe.	Ripen.	Ripe.	Unripe.	Ripe
Resinous chlorophyle,	0·27	—	0·03	0·08	0·05	—	0·04	0·02	—	0·08	0·0
Colouring matter,	—	—	—	—	not determined		—	—	0·10	—	—
Sugar,	0·63	11·61	17·71	24·81	1·12	18·12	Trace.	6·54	16·48	6·45	11·2
Dextrin,	4·22	4·85	5·53	2·06	6·01	3·23	4·10	4·47	5·12	3·17	2·6
Cellulose and pectose,	3·01	1·21	1·26	1·11	2·44	1·12	3·61	2·53	1·86	2·80	1·2
Albumen,	0·41	0·93	0·45	0·28	0·21	0·57	0·76	0·24	0·17	0·68	0·7
Malic acid,	1·07	1·10	0·45	0·56	1·75	2·01	2·70	2·03	1·80	0·21	0·9
Lime,	0·08	0·06	Trace.	Trace.	0.14	0·10	Very	little	else.	0·03	0·0
Water,	90·31	80·24	74·57	71·10	88·28	74·85	89·39	84·49	74·87	86·28	83·9
Citric acid,	—	—	—	—	—	—	—	—	—	—	—

It appears from these analyses, that the acids (whi here nearly all represented as malic acid) do not dimin quantity with the ripening of the fruit; and, therefor cording to these results, Liebig's hypothesis (Journ. de P et de Chimie, Tome 4, p. 85, 1844) that these acids ar verted into sugar, is unfounded. The decrease of the is *not real*, but the sugar increases in quantity and thu acid taste of the fruits is disguised. According to Be in several fruits these acids even increased in quantity.* of the constituents that decreased is dextrin; but, ac ing to the above analyses, this also is subject to excep But the diminution of dextrin is in no instance equal t increase of sugar.

A decrease is also apparent in the substances whic have quoted from Berard's analyses under the names of c lose and pectose. But this also gives no explanation o increase in sugar.

Can this sugar have been produced from carbonic a absorbed from the air? In my opinion this cannot be case, for it would then be necessary that in a short pe a considerable quantity of carbonic acid should have pa through the pericarp; while considering the rapid gro of the fruits this could hardly be possible, even although atmosphere consisted of carbonic acid alone.

The idea that the pectose of the fruits could be conver into sugar by the agency of the acids of the same fruits, is a

* In the berries of the mountain ash, however, the quantity of malic ac certainly decreasing about the time of ripening.

rently unfounded. If such a transformation really took place, it would not require in fruits the presence of acids. Turnips, carrots, beet, and mangold wurzel, are all roots that yield pectin and contain sugar, and in these no free acid is found. We have seen (Scheik. Onderz. D. III. p. 247) that pectose produces both sugar and pectic acid, and it would appear that, instead of pectic acid being converted into sugar, both these substances are produced simultaneously.

Considering the complex nature of pectose, and the present impossibility of explaining its formation from other substances, we are as yet unable to give a correct idea of the change of materials, with which the ripening of fruits is attended. We must take care, therefore, not to adhere to any fixed conception, until new facts shall have thrown more light upon this subject.

In order to conduct such investigations properly, the unripe fruits that are examined must be full grown; they must be separated from the plant, and then we must find out what changes the substances undergo while thus isolated.

This investigation, however, is attended with difficulties, not only because it is not easy to effect a complete separation of the several constituents, but also because at the time of ripening the fruit greatly increases in bulk, and, consequently, a very considerable quantity of substances is conveyed through the stalk; and, further, because at that period a very active change of materials takes place, supported by a strong evaporation; and, finally, because the two epochs of the development of fruit, viz., growth and ripening, sometimes coincide. It is well known, for instance, that by a strong summer heat, cherries, when nearly ripe, begin to swell very much and become ripe at the same time. This swelling arises from a supply of sap through the stalk; the cherries which have already a very red colour no more absorb carbonic acid from the air. All that they now receive, therefore, comes from the plant, and consequently the change which is now going on in the constituents of the fruit is made up of that produced in the existing and of that in the newly-supplied substances.

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He further thinks that ripe fruits have not an acid taste, because they contain a larger quantity of bases, by which the acids are saturated, and not because they are disguised by the sugar.*

So much for the *fleshy fruits* and *berries*.

The fruits of *leguminous* plants and many others, in general those containing starch, exhibit properties exactly opposite to those of the fleshy fruits, namely, before being ripe they contain much sugar and comparatively little starch; but when ripening they retain this quantity of sugar whilst that of the starch greatly increases.

We learn this from the composition of peas and beans. According to Einhoff unripe barley contains 15.97 per cent. of starch and 5.55 per cent. of sugar, and when ripe 67.18 per

* Fremy draws the following conclusions from his experiments—

1° The ripening of fruits is prevented by covering them with a varnish, which opposes both the influence of the air and the perspiration.

2° The conversion of the oxygen of the air into carbonic acid during the process of ripening is a phenomenon which seems to depend on the organisation of the fruit.

3° The gas existing in fruits is frequently a mixture of nitrogen and carbonic acid. Only those fruits that are still in the green state contain a considerable quantity of oxygen. This result is confirmed by the observations made on the respiration of fruits.

4° The tartaric acid contained in grapes is not produced by the modification of some other acid, as has been thought by some chemists, for this acid exists in the fruit, both in its first stage of growth and in the state of maturity.

5° Fruits growing in the presence of an alkaline liquid contain no perceptible quantity of sugar.

6° At the moment of ripening the acids of the fruits are partially saturated, and form salts of lime or potash.

7° The changes occurring in fruits after they have been taken from the tree belong to a period of decomposition, upon which the air exercises much influence.

8° There are some nitrogenous substances, either of animal or vegetable origin, by which the organic salts can be converted into carbonates. This peculiar property, which indicates how the alkalies are made to appear during the growth, may seem to explain the accumulation of carbonate of lime which is frequently found in the tissue of the leaves. Fremy on the Ripening of Fruits, in Journal de Chimie Medicale, Mars 1843, p. 132.

cent. of starch and 5.21 per cent. of sugar.* This starch may have been supplied in the form of dextrin, or, as it is in Indian corn (p. 236), in that of sugar;—the quantity of sugar does not diminish by the ripening of the fruits. There can be no question here as to the carbonic acid from the air having been converted into such a quantity of starch; the material must have been supplied through the stalk, and, therefore, from what takes place in barley and Indian corn inferences may be drawn as to what happens in fleshy fruits.

A large quantity of protein compounds, salts, &c., is supplied along with the sap, the water of which evaporates in the seed—the latter being a reason why such fruits require warm days for coming to maturity.

There is still another essential difference between these farinaceous seeds and fleshy fruits, that in the latter there is a very great increase of cells, whereas by the former solid substances are condensed and deposited within the cells, which do not much increase in number. This is an important distinction as proceeding from products so nearly allied as starch and cellulose.

Finally, we have to mention the *oleaginous* seeds, which, so far as they contain fatty matters, we have considered in p. 263. These at first contain starch, which they subsequently lose as the quantity of fat increases. This is a remarkable transformation of one substance into another, which must be attended with the separation of a large quantity of oxygen.

Something similar must take place in all seeds containing ethereal oils, such as anise, cumin, fennel-seed, &c. But it has not yet been discovered from what substances these ethereal oils are produced.

O. A Glance at the Mode of Production of Vegetable Substances.

The change of materials which is going on in plants em-

* These analyses of Einhoff are to be received with much distrust, in so far as the proportion of sugar is concerned. Mulder's deduction from them as to the persistence of the sugar is also, I believe, at variance with other known facts.—*J.*

braces all the transformations that are experienced by the food introduced into them from without, when it is converted either into parts of a definite form, or into such as are shapeless, belonging to the contents of cells and vessels, or into excretions. It is a difficult matter to produce anything like order in this wide field, in which hitherto so little has been done. The present state of science allows us only to throw upon it a few general glances.

It is usual to distinguish in the physiology of plants two kinds of changes, viz.: those that are comprehended under the name of the *nutrition*, and those under that of the *secretions* of plants. But this distinction is incorrect. It is true that certain peculiar substances are expelled from plants, but in the first place these ought then to be called *excretions* and not *secretions*, and secondly, no distinction can be drawn between what may be called *nutrition* and *secretion*.

I have retained neither the term nutrition nor that of *se-* or *excretion* in the usual sense. That which belongs to the necessary contents of the cells is equally entitled to the name of food of the plant, as what is capable of assuming a definite form, and consequently belongs to the persistent constituents of plants. It is even possible that a large portion of the solid parts of a plant must be considered nearly valueless as regards its life, and is rather an ultimate result of transformation than a chief requisite for the maintenance of its life. It is, no doubt, in this light that we must view, for instance, the incrusting layers of the ligneous cells which constitute such a great part of all woody plants. They seem to belong to the substances which may be wanting in plants, and which are not essential to their real character. The acids and sugar, on the contrary, which are found in fleshy fruits, are absolutely indispensable, and without these the fruits apparently could not exist.

Finally, there is a great number of secretions and excretions, which are often so essential to the peculiar manifestations of the life of certain families of plants, that they can by no means be considered as superfluous or injurious substances, and therefore only fit for excretion. Of this class are many ethereal oils, the opium in the poppy, &c.

If we look only to the first and last stages of the formations which take place in the vegetable kingdom it would appear to be an easy task to explain the prod of vegetable substances, seeing that the composition many of these is known. For this purpose it would seem be sufficient, on taking together the carbonic acid, amm water, ulmic, humic, geïc, apocrenic, and crenic acids, lect two or three of these for starting points, and from to construct, with the pen, the formation of every veg substance, as we have done with starch at p. 67. Citri ($C^4 H^2 O^4$) for instance, would then be a compound o bonic acid (CO^2) and water which has lost oxygen. Th

$$4\,CO^2 + 2\,HO = C^4 H^2 O^4 + O^6$$

Quinine $=(C^{20} H^{12} N O^2)$ would then be produced ulmate of ammonia, also with carbonic acid and water, following manner:—

	C	H	N	
1 of ulmic acid . . =	40	14		1
1 of ammonia . . . =		3	1	
1 of carbonic acid . . =	1			
7 of water . . . =		7		
	41	24	1	21
Deduct from this—				
1 of quinine*	20	12	1	
3 of quinic acid	22	12		1
	41	24	1	14
And there remain 7 of oxygen to be given off				7

We might proceed in this manner to build up wit pen the whole of organic nature. But physiological ch try is not a science of possibilities or probabilities; it science of certainties, and in the absence of certainti cannot advance by probabilities. The appearance of t is not truth itself. The word *knowledge* (or science) is derived from to *appear* but from *to know*. The most we

* Laurent's new formula for quinine is $C^{38} H^{22} N^2 O^4$.—*J.*

learn from these formular schemes is what must be excreted from the plant and what must enter into it, if we know first what is formed within the plant.

Science, therefore, will not advance one step by such indications of the existence of mere mutual relations between the various vegetable substances; and as we are yet unacquainted with the specific mode of their production, it will be best to confess our ignorance on this point, and to rest satisfied with the little that we at present know—patiently waiting for what will be discovered in future.

It is unquestionable that all parts of plants, except those into which the air can freely penetrate, have a general tendency to deoxidation, which is therefore just the opposite of the action that many chemical bodies undergo at a high temperature. This tendency is apparent from the production of substances poor in oxygen, such as many ethereal oils, or of those without any oxygen, as are a number of vegetable bases. This general tendency or struggle toward deoxidation,—of which we see the manifestation in the disengagement of pure oxygen into the atmosphere, and which we may therefore consider as a fact, although we know no more of it than why a red heat causes iron to assume an opposite tendency,—this tendency, I say, may afford a general explanation of the production of a great number of substances. For a thorough explanation, however, it would be requisite to pursue this production step by step—as we can do that of mellon, when we commence to heat blood with potash in an iron vessel, to mix the ferrocyanide of potassium produced with sulphur and to heat this mixture, to pass a current of chlorine through the sulpho-cyanide of potassium formed, and to heat the sulphocyanogen, from which mellon is at last produced. There is no reason why we should look for more explanation as to the formation of mellon, than as to that of tartaric acid, and if we do not understand the formation of the latter as well as that of the former, then we do not *know* how tartaric acid is formed.

The general constituents, if not of *all*, at least of the greater part of plants, are: cellulose, starch, inulin, lichen-

starch, gum, mucilage, dextrin, the various kinds of sugar and the substance constituting the horny albumen, all of which may be reduced to the formula C^{12} H^{10} O^{10} plus minus a certain quantity of water. We have further: pectose, of which the composition is still unknown; the two incrusting layers of the woody cells, the substance of the cuticle, of the corky tissue, and of some kinds of pith, all of which have been considered in Chapters VI. and VII. In these chapters I have also explained, as far as our present knowledge will allow, how the formation of these substances takes place, and also that of the fats, various kinds of wax, chlorophyle, and protein in all the different forms in which it occurs in plants.

We have still to consider the less general, sometimes even very rarely occurring constituents of plants. I shall confine myself to those of which we possess correct analyses, passing over, of course, the large number of substances that have not yet been analysed, and also those of which the composition is not yet sufficiently established.

P. Oxalic Acid.

Among the substances that are present in a considerable number of plants, is found oxalic acid in combination with lime. This oxalate of lime, which frequently appears under such beautiful forms, deserves our special attention. In some parts of plants that are very rich in starch, such as potatoes,* this salt is frequently wanting; but on the contrary, in the many laceous Cacteæ it is generally present. It is certain that oxalic acid occurs much more generally than any other vegetable acid; and besides, whilst the greater part of the other acids are confined to fruits, oxalic acid is found beyond the fruits, viz.: in the various species of sorrel in the form of binoxalate of potash, and as oxalate of lime in all sorts of plants.

This general appearance of oxalic acid is the more remarkable, because it is placed on the boundaries of organic bodies. It may be called an anomalous vegetable acid; since its affi

* Crystals of oxalate of lime have lately been observed to be at times very abundant in the interior of the potato.—*J.*

nity for bases is comparable with that of sulphuric acid; it is a product of decomposition, arising from the action of nitric and other acids on various neutral substances of the organic kingdom, such as sugar, &c., when carbonic acid is the accompanying product; and finally it is, like carbonic acid, free from hydrogen, and differs from this acid only by half an equivalent of oxygen.

If, in addition to all this, we take into consideration the indubitable facts, that plants absorb and decompose carbonic acid and give off oxygen, we are almost irresistibly led to believe that in the great number of plants which contain oxalic acid, the latter is actually formed from carbonic acid.

As to the manner in which this oxalic acid is produced from carbonic acid, we ascribe it to the general tendency of the constituents of plants to part with their oxygen. Every two equivalents of carbonic acid, therefore, that are absorbed, cause the emission of one equiv. of oxygen, whilst one equiv. of water is fixed, to produce oxalic acid ($C^2 O^3 + HO$.) Only in the presence of a base, like lime, this oxalic acid remains unaltered; but when no such base exists, it continues losing oxygen, and then it may produce other acids and other substances.

It can easily be proved that the oxalic acid in plants is actually formed from carbonic acid, and is not a product of the oxidation of sugar or any similar substance. In substances of a vegetable nature, in which salts of deutoxide of copper are reduced into those of the protoxide, in which carbonic acid is decomposed with disengagement of oxygen, in which phenomena of de-oxidation are seen very active, the formation of the most highly oxidised organic product by oxidation would appear a great absurdity. This oxalic acid is produced along with substances that contain little oxygen; whilst beyond the vegetable kingdom it can only be formed when there is an abundant and easy supply of oxygen to organic bodies.

If, therefore, anything is certain regarding the formation of any organic substance, it is this, that oxalic acid is produced from carbonic acid by the loss of oxygen.

Q. Of the Acids

We may now consider it as a
greater part of organic acids are
polybasic acids are of this clas
complex at the ordinary tempera
exposed to heat or in certain pecu
for instance, *citric acid* is exposed
of silver, it is readily changed in
aconitic acid, for

Citric Acid. Citric.
$3\,(C^4\,H^2\,O^4) = 2\,(C^4\,H^2\,O^4)$
$C^{12}\,H^5\,O^{11}$ +

—as was pointed out by Berzeli
354.) Its constitution is stated
et de Physique) to be as follows:—

Oxalic acid, ...
Acetic acid, ...

Oxal-acetic acid,...

This idea, however, is not suppo
Tartaric acid, 2 ($C^4\,H^2\,O^5$) is,
de Chim. et de Phys., Tome 5, p. 3
of oxalic and 1 equiv. of acetic ac
that the hydrogen is derived from
from the oxalic acid. Thus to

2 of oxalic acid..... (C^2 O
Add 1 of acetic acid.....

And deduct one of water (HO

And there remain.....
which is 2 ($C^4\,H^2\,O^5$) or two of ta
Such representations do not as
we may consider it as a true state

cannot be regarded as a simple group; but that they consist of a number of groups united into one whole, equal to the number of equivalents of the bases with which the polybasic acids combine.

To this class of acids belong tartaric and meconic acids.

Some acids exist in fruits, and it is worthy of remark, that these bear all a simple relation to one another.

Citric acid, ... $C^4 H^2 O^4 \times 3 = C^{12} H^6 O^{12}$
Malic acid, ... $C^4 H^2 O^4 \times 2 = C^8 H^4 O^8$
Tartaric acid, ... $C^4 H^2 O^5 \times 2 = C^8 H^4 O^{10}$
Paratartaric acid, ... $C^4 H^2 O^5$

If it is fully proved that the berries of the mountain-ash first contain tartaric acid and subsequently acquire malic acid, then we are led to the conclusion, that by actions which give rise to the disengagement of oxygen, one vegetable acid may be converted into another. This brings us, as it were involuntarily, to the idea, that the carbonic acid in the sap, either with or without a previous transformation into oxalic acid, by a progressive deoxidation and combination with water, forms first tartaric acid (or paratartaric acid) and then citric or malic acid.

Citric acid is of a complex nature, and consists of

$$2 \times C^4 H^2 O^4 + C^4 H O^3$$

as is proved by the established analysis of the silver salt and the further researches made by Berzelius. Now if malic acid, $C^4 H^2 O^4$, has been produced from tartaric acid, this again from oxalic acid, and the latter in its turn from carbonic acid, then we may likewise extend the idea here proposed to aconitic and fumaric acids, both of which consist of $C^4 H O^3$. As far as we know at present, therefore, the acids of the fruits, and some others of a similar composition, may be produced from carbonic acid and water, when these are brought into the circle of change of materials.

This idea obtains additional support, if we bear in mind, that although oxidised products of some substances, containing but little oxygen or none at all, may be formed in those parts which have a free communication with the atmosphere by means of air canals;—we are, however, by no

means warranted to assume, that in parts continually
influences of a deoxidising nature, such a first deg
oxidation could take place as would be necessary to c
one of the general constituents of plants, such as dextri
malic or tartaric acid.

These acids, after being once produced in the frui
persistent there, and when the fruits are ripening, th
only more and more enveloped by the increasing qu
of sugar.

R. Acids generally diffused in Plants.

There are besides those above named, the

Aconitic acid, ...C^4 H O^3
Fumaric acid, ...C^4 H O^3

There are some other acids also existing either in c
parts of plants, or throughout some particular plants, vi

Meconic acid,.....C^{14} H^4 O^{14} in opium.
Quinic acid, ...C^7 H^4 O^4 in Peruvian bark.
Veratric acid,.....C^{18} H^9 O^7 in seeds of sabadi
Valerianic acid, ...C^{10} H^9 O^3 in valerian.
Roccellic acid, ...C^{17} H^{16} O^4 in roccella tinctor
Chinovic acid, ...C^{38} H^{29} O^9 in China nova.

No explanation can be given as to the manner in w
these acids are formed. Of valerianic acid we only know
it may also be produced artificially from the oil of potat
rit (hydrate of oxide of amyl.) C^{10} H^{11} O + H O, by t
ing it with potash, hydrogen being given off, and water e
ing into combination.

S. On Tannic Acid.

This acid (C^{18} H^5 O^9), which is so diffused through var
parts of plants, in some even accumulated in large quan
is very often a companion to starch, or is accompanied b
This tannic acid, on being boiled with dilute sulphuric
gives rise to the production of gallic acid and grape su
which is partly converted into humic acid. Thus from

1 eq. of tannic acid, $C^{18}\ H^{5}\ O^{9}$ take
2 " of gallic acid, $C^{14}\ H^{2}\ O^{6}$ and there

Remain $C^{4}\ H^{4}\ O^{3}$

When water unites with this, grape sugar is produced.

Tannic acid, on being exposed to oxygen, is converted into gallic and carbonic acids, the latter equal in volume to the oxygen absorbed. The four equivalents of the body represented as $C^{4}\ H^{4}\ O^{3}$, absorb eight equivalents of oxygen, and produce four of carbonic acid ($4\ CO^{2}$).

If, in addition to these facts, we bear in mind that when powdered gall nuts are moistened with water, gallic acid, carbonic acid, and alcohol are formed, and that by destructive distillation gallic and tannic acid yield the same products, then it becomes probable that when gallic acid is found in a plant, it is the product of the decomposition of tannic acid, effected without the co-operation of the plant. This decomposition may either produce nothing but grape sugar by combination with water, or when oxygen is absorbed, carbonic acid may also be disengaged.*

We learn from this fact, that either gallic acid and grape sugar, or gallic and carbonic acids together, are produced from tannic acid severally by the action of sulphuric acid and of oxygen; that in tannic acid as in salicin we may conceive the existence of grape sugar, and that, therefore, tannic acid may be considered as a combination of gallic acid and grape sugar. This at least appears to follow from the analyses of tannic acid that we at present possess.

When either tannic or gallic acid is suddenly and strongly heated, it produces one or more equivalents of pyro-gallic acid ($C^{2}\ HO$). On being cautiously heated to 482° F., both tannic and gallic acids are converted into meta-gallic acid ($C^{6}\ H^{2}\ O^{2}$).

This perfect identity of peculiar compounds, produced by pyro-chemic decomposition, especially in connection with the

* When tannic acid is present in leaves, it must disengage carbonic acid with absorption of oxygen. In this manner astringent leaves may actually take up oxygen and give off carbonic acid.

preceding properties, seems fully to establish the pre-
tence of gallic in tannic acid.*

Tannic acid is subject to still another change, which i
markable in a physiological point of view, viz., its conve
into apotheme. This change takes place both in and be
the plant, and consists in a transformation of the constit
of tannic acid, which is attended by the absorption of ox
and the disengagement of carbonic acid, without the co
ration of any organ of the plant.

This change is the cause of the brown colour of barks
taining tannic acid, such as Peruvian bark, that of the
nut tree, willow tree, oak tree, cinnamon tree, &c.
chesnuts themselves, when recently taken from the per
appear white, but they soon become brown. The bea

* Since the above was written, Mulder has established a much closer r
between the tannic and gallic acids than is indicated in the text. If
acid be digested in diluted muriatic acid at 212° for several days, in
from which air is completely excluded, it is entirely changed into gal
without the production of any other substance. This observation has l
new analysis of the tannic acid, from which the formula, C^{28} H^{9} O^{17}, h
deduced.

The change of the tannic into gallic acid (C^{7} H^{3} O^{5}, or C^{7} H^{1} O^{3} +
is therefore represented as follows :—

	C	H	O
To 1 of tannic acid	28	9	17
Add 3 of water		3	3
And 4 of gallic acid remain	28	12	20

—a conversion which is very simple.

The action of sulphuric acid upon tannic acid, in the presence of the
to convert it into gallic acid, with the production at the same time of a
tity of ellagic acid and a blackening of the liquid. The ellagic acid
duced from the tannic through the influence of the oxygen of the air.
to—

	C	H	O
1 of tannic acid	28	9	17
Add 2 of oxygen from the air			2
	28	9	19
And deduct 5 of water		5	5
There remain	28	4	14

—which are equal to two of ellagic acid, C^{14} H^{3} O^{7}.

The results of this research are very interesting, and are detailed in Mu
Scheikundige Untersuchungen, iv., p. 640, *et seq.*—*J.*

change effected in mahogany wood, by exposure to the air, is owing to the same cause.

In such barks, therefore, as give ready access to the air, tannic acid undergoes the same change as when a solution of it is evaporated in the air. It is converted into apotheme The browner a bark is, the less tannic acid it contains, for the acid has been so much the more converted into apotheme.

T. Cinnamic Acid.

This acid, which is represented by the formula $C^{18}\ H^{7}\ O^{3}$, must necessarily contain oil of bitter almonds, and hence it must consist of $C^{14}\ H^{6}\ O^{2} + C^{4}\ HO$. Erdmann and Marchand observed that when cinnamic acid is heated with sulphuric acid and bi-chromate of potash, oil of bitter almonds was produced, which was not the case with benzoic acid when so treated (Journ. Bd. 26, S. 497). In this manner, however, only a small portion of the oil of bitter almonds can be formed, and its presence may serve as a means of distinction between cinnamic and benzoic acid; but by the oxygen that becomes free in this operation, the greater part of the oil of bitter almonds must be converted into benzoic acid. This experiment, however, affords a strong proof that cinnamic acid actually contains hydruret of benzyl, and that it is consequently a complex acid.

The conversion of cinnamic acid into nitro-benzoic acid, by the prolonged action of nitric acid, leads us to the same conclusion. (Bulletin, 1839, p. 380.)

Cinnamic acid is an oxidized product of decomposition of oil of cinnamon. $C^{18}\ H^{8}\ O^{2}$ (hydruret of cinnamyl) is formed by the replacement of one equivalent of hydrogen by one of oxygen, that is, by the action of the oxygen of the air. The oily substance, or hydruret of cinnamyl itself, is produced from oil of cinnamon in the following manner:—

	C	H	O
To 3 equiv. of oil of cinnamon,	60	33	6
Add 6 of oxygen, ...			6
And we have, .. .	60	33	12

which are equal to—

α resin, ...
β resin, ...
hydruret of cinnamyl,
5 equiv. of water, ...

Nothing else, therefore, is produced
cinnamon but C^{20} H^{10} O + HO (hy
and the whole of the resins and cin
are products of the oxidation of this

Benzoic acid, C^{14} H^5 O^3, is unque
similar manner in benzoin. The vol
is first converted into hydruret of
subsequently becomes benzoic acid,
air, has not as yet been isolated.

U. Salicin and Phl

1° The most recent experiments of
salicin consists of uncrystallisable s
stance which he calls saligenin. Th

Glucose (uncrystallizable sug
With Saligenin, ...

From Salicin, ...

These two substances may be sepa
means of synaptase. After having
hours, the mixture is shaken with et
stand. The ether dissolves the salig
large shining plates ; produces a sub
colour, when mixed with a salt of pe
dilute acids is converted into sali-r
picric acid, and by other oxidizing
of salicyl. By the action of weak
combination is produced of glucose
C^{52} H^{35} O^{31}. This substance, whic

* Comptes Rendus, 24 Juillet

treated with synaptase, acids, or alkalis, is separated into glucose, hydruret of salicyl, and water. Thus—

Glucose,	... ...	$C^{24}\ H^{20}\ O^{20}$
Hydruret of salicyl,	...	$C^{28}\ H^{12}\ O^{8}$
Water,	... ...	$H^{3}\ O^{3}$
Helicin,	... ...	$C^{52}\ H^{35}\ O^{31}$

Piria thinks, that when oxidizing substances (such as bichromate of potash and sulphuric acid) act upon salicin and produce hydruret of salicyl, the saligenin must lose hydrogen, and the whole of the glucose must be oxidised.

Salicin, therefore, is a complex substance, and saligenin ($C^{28}\ H^{16}\ O^{8}$ $2 \times C^{14}\ H^{8}\ O^{4}$) may be considered as a combination of the elements of water with those of hydruret of benzyl, $C^{14}\ H^{6}\ O^{2} + 2HO$.

It appears from this, that benzoic acid, oil of spiræa, cinnamic acid, and salicin, contain one common organic group. The two last bodies, however, are complex compounds.

2. Phloridzin, $C^{42}\ H^{24}\ O^{24}$, is also a complex substance, which is in so far related to salicin that both contain fruit-sugar. By digestion in dilute sulphuric acid, the phloridzin is decomposed, the fruit-sugar is dissolved by the liquid, and a substance is separated, known by the name of phloretin ($C^{30}\ H^{12}\ O^{10}$). Thus –

Phloretin	...	$C^{30}\ H^{12}\ O^{10}$
Fruit-sugar	...	$C^{12}\ H^{14}\ O^{14}$
Phloridzin	...	$C^{42}\ H^{26}\ O^{24}$

When phloridzin is exposed to the joint action of ammonia and oxygen, the process by which orcein is prepared from orcin, it yields a fine blue substance, which Staas has called phloridzein. Thus—

Anhydrous phloridzin,		$C^{42}\ H^{24}\ O^{12}$
Ammonia,	...	$H^{6}\ N^{2}$
Oxygen,	...	O^{2}
Phloridzein,	...	$C^{42}\ H^{30}\ N^{2}\ O^{24}$

Phloridzin, therefore, is a complex substance containing grape-

sugar, and yet it forms with ammonia and oxygen a dark bl product, in which the elements of this sugar are present.

These results enable us to form an idea as to the nature organic groups. It is evident from the case of phloridz that these groups are often very complex. We learn fr this, in the second place, what services sugar may perform the production of new substances. And lastly, it teach us how variously those substances may be composed whi are developed in plants as colouring matters.

There is in plants a large number of so-called bitt neutral substances, which contain no nitrogen, and whi are classed in organic chemistry with salicin and phloridz We cannot, however, treat of them here, because they ha not been sufficiently studied. To these belong anemonin, b peridin, monesin, myrrhoïdin, narcitin, parin, syringin, l tucin, smilacin, stramonin, taraxacin, rumicin, &c. For these I refer to the manuals of Chemistry.

X. Succinic Acid.

This acid, which is represented by the formula $C^4 H^2 O$ may be formed either from margaric or from stearic acid oxidation with nitric acid.*

It may also be produced from wax in the same way. Th wax is first converted into an oil, which subsequently di appears, whilst nothing but succinic acid is left.†

If for myricin we assume the formula $C^{20} H^{20} O$, and sup pose the whole of its carbon to be included in the succin acid, then we have $5\ C^4 H^2 O^3 = C^{20} H^{10} O^{15}$, whence appears that 10 equivalents of oxygen are required to oxidi 10 equivalents of hydrogen in the myricin, and 14 of oxyg to supply it with the oxygen necessary to convert it into su cinic acid.

The succinic acid, therefore, which (according to Unve dorben, Bobat, and Lecanu) is found in amber, and in the r sins of living coniferæ, may be a product of the oxidation

* Liebig, Chimie Organique, p. 543.

† Ronalds, in Ann. der Chem. und Pharmacie, Bd. 43, L. 356.

some waxy or fatty substance in plants. We have the more reason to attach some importance to this view of the production of succinic acid, because it exists in old cumin-oil, where it is unquestionably a product of oxidation *

In whatever plants it is found, it always exists in the external parts,—in those to which the air has ready access,—and there it is mixed with resins which we know to be produced by oxidation.

V. *Ethereal Oils.*

Ethereal oils and resins are connected as regards their origin; for the latter are produced from the former by the influence of the oxygen of the air. Ethereal oils are for the most part formed by the change of materials which takes place in the leaves. In mint and similar plants the oil is in the leaves, and is there preserved, because the plant is full of watery liquid. This production of oil is accompanied by the disengagement of oxygen from a substance in the leaves with which we are unacquainted. In fennel and anise plants this formation of ethereal oil also takes place in the seed, which must therefore give off oxygen during the ripening. In roses and other plants the same function is performed in the flowers; and hence it is, doubtless, that odoriferous flowers emit oxygen. True it is, that ethereal oil is also found in calamus and some other roots, but the examples of such a function in the roots are far less numerous than of its occurrence in leaves and fruits, in a word in those parts which give off oxygen. The ethereal oils diffused through the sap descend from the leaves through the bark, and supply to these the oils that are found there either unchanged,—for instance, oil of cinnamon, turpentine, &c.; or in an oxidized state, as resins, gum-resins, and balsams,—for instance, benzoin, Peru-balsam, storax, &c.

The best known ethereal oils are the following:—

1. Oil of elemi, C^{10} H^8 (Deville.)
2. Oil of lemons, C^{10} H^8 (Blanchet and Sell.)
3. Oil of oranges, C^{10} H^8 (Voelckel.)

* Chevallier in Journ. de Chim. Medicale, 1824, Jan.

4. Oil of copaiba balsam, C^{10} H^8
5. Oil of calamus, C^{10} H^8 (Sch
6. Oil of fennel, C^{15} H^{12} (Cah
7. Oil of juniper, C^{15} H^{12} (Sou
8. Oil of cubebs, C^{15} H^{12} (Sou
9. Oil of cloves, C^{20} H^{16}.
10. Oil of turpentine, C^{20} H^{16} (
11. Oil of sabine, C^{20} H^{16} (Dun
12. Oil of black pepper, C^{20} H^{16}
13. Oil of pennyroyal, C^{10} H^8 O
14. Stearopt of the oil of basili
(Dumas and Peligot.)
15. Oil of rosemary, C^{45} H^{38} O
(Kane.)
16. Oil of bergamot, 3 (C^{10} H^8)
17. Caryophyllin, C^{20} H^{16} O^2 (
18. Oil of valerian, { Borneen C / Valerol C
19. Oil of cajeput, C^{10} H^9 O (B
20. Oil of olibanum, C^{35} H^{34} O
21. Oil of cumin, { Cyminum C^2 / Cuminol C^{20}
22. Tolen (the volatile oil of Tolu
23. Stearopt of rose oil, C H (B
24. Stearopt of oil of peppermin
25. Oil of rue, C^{28} H^{28} O^3 (Wil
26. Stearopt of oil of marjorum,
27. Stearopt of oil of nutmeg, C
28. Oil of cinnamon, C^{20} H^{11} O
29. Concrete oil of anise (also
C^{20} H^{12} O^2 (Dumas, Cahou
30. Oil of spiraea (salicylous acid
31. Cinnamein (in Peru and
(Fremy.)
32. Helenin, C^{15} H^{10} O^2 (Gerh

* Valerianic acid is C^{10} H^9 O^3. It seem
plant from borneen + O^3.

† According to de Lalande, the same oil,
tained when camphor is distilled with anhy

33. Oil of cina-seed (two oils unequally volatile), $C^{18}\ H^{15}\ O^{2}$ (Voelckel.)
34. Cubebin, $C^{17}\ H^{9}\ O^{5}$ (Soubeiran and Capitaine.)
35. Oil of sage, distilled at 266° F. $C^{12}\ H^{5}\ O$ (Roehleder.)
" at 266° to 284° $C^{13}\ H^{15}\ O^{2}$
" at 302° F. $C^{12}\ H^{10}\ O$
$= 2\,(C^{6}\ H^{24})\ O$
$3\,(C^{6}\ H^{5})\ O^{2}$
$2\,(C^{6}\ H^{5})\ O$
36. Anemonin, $C^{15}\ H^{6}\ O^{6}$ (Fehling.)
37. Oil of origanum, $C^{30}\ H^{40}\ O$ (Kane.)
38. Coumarin (stearopt from Tonka beans), $C^{18}\ H^{7}\ O^{4}$* (de Lalande.)
39. Oil of artemisia, $C^{32}\ H^{21}\ O^{3}$ (Laurent.)
40. Oil of cedar (solid) $C^{32}\ H^{26}\ O^{2}$ (Walter.)
do. (liquid) $C^{32}\ O^{24}$
41. Stearopt of bergamot oil, $C^{3}\ HO$ (Mulder, Ohme.)

Although we know little as yet of the history of the ethereal oils, we are warranted to consider the following facts as established:—

We find in them the following hydro-carbons:—

$C^{2}\ H$ as in No. 31.
$C^{3}\ H$ ..... No. 41.
$C^{5}\ H^{4}$ ..... No. 1 to 19.
$C\ H$ ..... No. 23.

Only part of these contain no oxygen, as Nos. 1 to 12. Others are oxides or hydrates of this combination, as Nos. 13, 14, and 15, or hydrated oxides, as No. 30.

Those that deviate from this simple composition may be mixtures of two or more others, for it is very difficult to obtain them in a pure state.

It cannot be doubted that the hydro-carbons here enumerated ought to be called radicals, for as such they form combinations with other substances, such as hydrochloric acid. Their elements however, cohere so slightly, that part of the

* This differs from cinnamic acid ($C^{18}\ H^{7}\ O^{3}$) only by one equivalent of oxygen. When coumarin is treated with potash, an equivalent of hydrogen is driven off, and coumaric acid, $C^{18}\ H^{7}\ O^{4}$, produced.

hydrogen may be easily exchanged for oxygen, the rest remaining behind. An instance of this may be given in the production of the resins of the turpentine, $C^{40}\ H^{36}\ O^4$, which have been formed from $8 \times C^5\ H^4 = C^{40}\ H^{32}$.

For this reason, the ethereal oils in plants are frequently altered by the influence of the air, and it is difficult to obtain them in the same state in which they originally existed in the plant.

There can be no doubt that the substances from which the ethereal oils in plants are produced belong to the general constituents of plants, for we find them every where. Now, seeing it may be considered as proved that fats are produced from starch, and since ethereal oils are in so far similar to fats that they contain little oxygen—and must, therefore, have been formed under similar circumstances,—we may safely conceive that they originate from one of the soluble combinations of $C^{12}\ H^9\ O^9$, + H O, (starch, dextrin, &c.) through its exposure to the general de-oxidising influence which prevails in plants. At present we cannot go farther.

This conception, however, excludes the idea that there should be a variety of *secreting organs* corresponding to the variety of ethereal oils. On the contrary, we ascribe all their differences to small modifications of the circumstances by which the same cellular contents may be influenced,—in the same manner as a slowly burning substance may yield quite different products, merely in consequence of small differences of temperature. The nature of the combinations of carbon and hydrogen, with or without oxygen, is as much determined by the impression which is imparted to the elements by the continual loss of oxygen expelled from the plant, as the temperature to which wood is exposed determines whether it shall yield acetic acid and different gaseous and liquid hydro-carbons, or simply carbonic oxide, carbonic acid, water, ammonia, and carbon.

We need scarcely point out that the formation of ethereal oils in plants is an abundant source of the oxygen disengaged. If they are directly or indirectly produced from $C^{12}\ H^9\ O^9$ + H O, then there is certainly an opportunity

for the production of various new substances, but a large quantity of oxygen will at the same time be set free;—for, with the exception of the small portion of acids, which are but sparingly found in plants, and exist in considerable quantity only in fruits,—there are no substances, or at least none of general occurrence, that contain so much oxygen as the group,

$$C^{12}\,H^{9}\,O^{9} + H\,O \text{ (Starch, dextrin, sugar, \&c.)}$$

When from this a compound $C^{5}\,H^{4}$ is produced, there remains $C^{7}\,H^{5}\,O^{9}$; that is, a group containing nearly as much oxygen as tartaric acid, $C^{8}\,H^{4}\,O^{10}$,—an acid in which more oxygen is present than in any other organic acid, with the single exception of oxalic acid. For whatever purpose, therefore, the group $C^{7}\,H^{5}\,O^{9}$ may be employed, whatever substance may be formed from it, oxygen must be liberated, because all that can be produced from it contains *less* oxygen.

If, however, we consult observation, we find that the formation of ethereal oils is not attended with these secondary productions. In pine-wood, for instance, we find no secondary product at all, much less one of which the quantity can be compared with that of the produced oil of turpentine,—for the resin is a product of oxidation *from* the oil itself. We are therefore warranted in concluding, that whatever substance, by its de-oxidation, may give rise to the production of ethereal oils, it in most cases yields *no other* product,—and that, if the oil is one of the class $C^{5}\,H^{4}$, the decomposition of $5 \times C^{12}\,H^{9}\,O^{9} = C^{60}\,H^{45}\,O^{45} + 3\,H\,O = C^{60}\,H^{48}\,O^{48}$, must produce $12 \times C^{5}\,H^{4} = C^{60}\,H^{48}$, and consequently 48 equivalents of oxygen must be disengaged.

A great number of ethereal oils are mixtures of two different ones, one of which has generally a greater tendency to combine with oxygen, and sometimes to form a stearopt, than the other. In such a case, the oil seems to have originated not from one but from a mixture of two substances.

The ethereal oils that contain nitrogen are compound groups, produced by the de-oxidation of at least two substances;—but from what substance their nitrogen has been derived we have no ground for stating. They do not appear to occur as such in the plant.

Lastly, caoutchouc, which, according to Faraday's a
has the composition C^{10} H^{9}, may in some degree be
dered as related to ethereal oils in its origin, because i
sents an analogous group. It is known that this cao
is of general occurrence in plants containing milk-sap.

Z. Fats.

It may be considered as sufficiently established tha
fats in plants are formed from starch, through the in
of de-oxidising agencies. When it has accumulated, o
it is not subject to this influence, it is either partly
at all converted into fat (see p. 264). We cannot ass
all fats originate from starch, because the fact has
been proved by observation.

As regards this production of vegetable fats and th
tual relations, enough has been said at p. 247. I th
refer to that place, and I would here only state,—as l
connexion with what has been said respecting the e
oils,—that the radical of by far the greater number of
pears to be CH, and that they may therefore in this
be compared with the stearopt of nutmeg oil, C^{16} H
and with the oil of ruta graveolens (garden-rue) C^{28}
Myristic acid, for instance (p. 250), has the composit
H^{28} O^{3} + HO.

Although the vegetable fats differ from the ethe
both in chemical character and properties, yet the o
both is intimately related, inasmuch as they seem to
duced from the generally diffused group C^{12} H^{9} O^{9}, a
from different members of this group.

AA. Resins.

I have already more than once remarked that re
produced from ethereal oils. This appears in the most
manner from the mode in which they are found. F
of turpentine, for instance, after all the resin has be
rated by distillation, the same resins may be prep

those obtained from pine-wood. There are many oxidizing influences by which ethereal oils are converted into resins. The natural balsams, which are mixtures of resins and oils, are in course of time entirely changed into resins.

A knowledge of balsams and resins is of great importance in throwing light upon the ethereal oils. We learn from peru-balsam, storax, &c.—which have been formed in the plant from oil alone by the action of the air,—what a complete mixture it must have been that gives rise to the existence of so many different substances; for these substances have been produced from the oil by *the same* influences, and cannot therefore have originated from one radical. Gum lac, guiacum, copal, and various others, equally indicate that the oil which has produced these compound mixtures must itself have been of a complex nature.

We need not remark that these resins owe their existence to ethereal oils, which have a very great tendency to absorb oxygen, by which they differ from many other oils. It has already been stated (p. 816), that part of the hydrogen only is replaced by oxygen.

For the last-named reason it is not difficult to judge of the composition of the oil from which a certain resin has been produced. From what we know of the resins of benzoin, it appears that in some of them the substitution of oxygen for hydrogen may amount to a considerable proportion.

β Resin of benzoin. $C^{40}\ H^{23}\ O^9 = C^{40}\ (H^{32} - H^9)\ O^9$. Nine equivalents of hydrogen in $8 \times C^5\ H^4$, have therefore been replaced by nine of oxygen.*

γ Resin of benzoin, $C^{30}\ H^{20}\ O^5 = C^{30}\ (H^{24} - H^4)\ O^4 + O$. In this case four equivalents of hydrogen from $6 \times C^5\ H^4 + O$ have been replaced by four of oxygen. The α resin of benzoin is a combination of the two former, $= C^{40}\ H^{23}\ O^9 + C^{30}\ H^{20}\ O^5 = C^{70}\ H^{43}\ O^{14}$.

To this class belongs also the electro-negative resin of copaiva balsam, of which, according to Fehling, the formula is $C^{40}\ H^{27}\ O^5 + HO$; for $C^{40}\ (H^{32} - H^5)\ O^5$ is equivalent to

* I have deducted one equiv. of hydrogen from the formula of Van der Vliet (Bulletin, 1839), which agrees with the results of the analyses.

$8 \times C^5 H^4 + O^5$,—5 equivalents of hydrogen replace of oxygen.

According to Filhol, the α, γ, and ε, resins of copaiv sam are oxides of 8 times the radical $C^5 H^4$, in which one equivalent of oxygen has been substituted for one drogen.

$$\left.\begin{matrix}\alpha \\ \beta\end{matrix}\right\} C^{40} H^{31} O^5$$
$$\gamma \quad C^{40} H^{31} O^3$$
$$\varepsilon \quad C^{40} H^{31} O^2$$

The same remark applies to the crystallisable resin paiva balsam, which, according to H. Rose, is represent the formula

$$C^{45} H^{35} O^4 = 9 \times C^5 H^4 = C^{45} (H^{36} - H) O^4.$$

The composition of sylvic acid (obtained from turpe by Trommsdorff), of pinic acid (from turpentine, by H. of colophan (from colophonium, by Blanchet and Sell) of a resin of copaiva (by H. Rose), is represented by th lowing formula:—

$$C^{40} H^{30} O^4 = C^{40} (H^{32} - H^2) O^4$$

—in which, therefore, two equivalents of hydrogen a placed by two of oxygen, whilst the two remaining eq lents must be considered as oxidising oxygen.

According to Hess, the composition of betulin is

$$C^{20} H^{17} O^4 = 4 \times C^5 H^4 + O^3 + HO.$$

According to H. Rose, the resin of elemi is represent the formula

$$C^{20} H^{16} O^2 = 4 \times C^5 H^4 + O^2.$$

To the resins which can be reduced to these simple for belong the crystallised resin of Euphorbium,

$$C^{14} H^{12} O \text{ (H. Rose)} = C^{15} H^{12} O \text{ (?)}$$

—the resin from Tolu balsam, $C^{18} H^{10} O^5$ (Deville), in w balsam Deville found, besides cinnamein, and benzoic cinnamic acids, a peculiar oil, having the composition C^2 If we calculate for the resin the formula $C^{24} H^{13} O^7$, also agrees with the result of the analysis, then we hav $(H^{18} - H^5) O^7$, or $6 \times C^4 H^3$, in which, therefore, 5 eq lents of hydrogen would be replaced by 5 of oxygen;

consequently, the resin contains 2 equivalents of oxidizing oxygen and 5 replacing an equal number of equivalents of hydrogen.

The nature of the isolated groups of resins which are found in some isolated cells is not yet known. It is probable that these have also been formed from ethereal oils by the action of oxygen supplied from adjoining parts. In the same manner, the aloe resin in the elongated cells may have been formed from some ethereal oil oxidised by the oxygen which is disengaged in the interior of the plant, and thus the oxygen from the atmosphere is not always a requisite for the transformation of ethereal oils into resins.

BB. Vegetable Alkalis.

This class of bodies is as yet but little known. Although we are well acquainted with their composition in the hundred parts, yet almost no investigations have been made into their constitution. As it was found that the capacity of saturation was not regulated by the number of equivalents of oxygen, but by those of nitrogen, it has been thought that they are composed of a non-nitrogenous group and ammonia. This opinion is in accordance with the combinations which all these bodies form with chloride of platinum. The composition of some of these alkalis is certainly such that they may be considered as different oxides of the same radical. If, for instance, we eliminate the nitrogen from the formula in the state of ammonia, we find a very simple relation between cinchonin and chinin.

Cinchonin, $C^{20} H^{12} N O = C^{20} H^{9} O + N H^{3}$

Chinin, $C^{20} H^{12} N O^{2} = C^{20} H^{9} O^{2} + N H^{3}$

And if we take into account an equivalent of water, this being usually present in these compounds, then we find—

Cinchonin $= C^{20} H^{8}$

Chinin $= C^{20} H^{8} O$

A similar relation exists between codein and morphin:

Codein, $C^{35} H^{20} N O^{5} = C^{35} H^{17} O^{5} + N H^{3}$

Morphin, $C^{35} H^{20} N O^{6} = C^{35} H^{17} O^{6} + N H^{3}$

And if here also we subtract an equivalent of wate
have for—

Codein..... $C^{35}\ H^{16}\ O^{4}$
Morphin ..... $C^{35}\ H^{16}\ O^{5}$

Between these vegetable alkalis, therefore, the same si
relation exists as between protein and its bi- and tri-oxi

But we are yet far from having discovered by this re
ing the nature of these bodies. Yet we shall first ana
some of them according to this view :

Strychnin, $C^{44}\ H^{24}\ N^{2}\ O^{4} = C^{44}\ H^{16}\ O^{2} + 2\,(N\,H^{3} +$
Brucin, $C^{44}\ H^{25}\ N^{2}\ O^{7} = C^{44}\ H^{17}\ O^{5} + 2\,(N\,H^{3} +$
Narcotin, $C^{40}\ H^{20}\ N\ O^{12} = C^{40}\ H^{16}\ O^{11} + N\,H^{3} +$
Piperin, $C^{34}\ H^{19}\ N\ O^{6} = C^{34}\ H^{15}\ O^{5} + N\,H^{3} +$
Jernin, $C^{60}\ H^{45}\ N^{2}\ O^{5} = C^{60}\ H^{37}\ O^{3} + 2\,(N\,H^{3} +$
Berberin, $C^{42}\ H^{26}\ N\ O^{16} = C^{42}\ H^{22}\ O^{15} + N\,H^{3} +$
Chinovatin, $C^{46}\ H^{27}\ N^{2}\ O^{8} = C^{46}\ H^{19}\ O^{6} + 2\,(N\,H^{3} +$
Harmalin, $C^{24}\ H^{13}\ N^{2}\ O = C^{24}\ H^{6} + N^{2}H^{6} +$

We see, from this enumeration, that the non-nitrogen
constituent of strychnin, $C^{44}\ H^{16}\ O^{2}$, and that of bru
$C^{44}\ H^{17}\ O^{5}$, if it really exists in them, may be represented
$C^{44}\ H^{16}\ O^{2}$ and $C^{44}\ H^{16}\ O^{2} + O^{2} + HO$, and, therefo
that there seems to be a relation between them as simple
that between codein and morphin, and between cincho
and chinin.

In narcotin we again find the same simple relation.
composition is represented by the formula :

$$C^{40}\ H^{16}\ O^{11},$$

and if we place beside this the formulæ for cinchonin
chinin doubled, we have :

Cinchonin,..... $C^{40}\ H^{16}$
Chinin, ... $C^{40}\ H^{16}\ O^{2}$
Narcotin, ... $C^{40}\ H^{16}\ O^{11}$

As to the others we can at present say nothing.

Although I have thus reduced the vegetable alkalis to
nitrogenous substances, and represented the nitrogen in
form of ammonia, I must expressly mention that in doin
my only intention has been to afford an easier view of
relation of their elements.

Liebig has made an experiment, which is conclusive against the presence of ammonia in these bodies. According to this, vegetable alkalis, when decomposed by means of nitric acid, do not yield nitrate of ammonia, which they ought to do if they contained ammonia. He thought that they might be compounds of amid, but this again is disproved by their not yielding ammonia with caustic potash.

Redtenbacher and Wertheim have undertaken an extensive investigation of these substances. As a preliminary result of the composition of piperin they mention (Annalen der Chemie und Pharmacie, Mai 1845, S. 254) that piperin is to be considered as a neutral compound of a nitrogenous acid with anilin. Narcotin, on the contrary, should be a neutral compound of a non-nitrogenous acid with a peculiar base. The narcogenin of Blyth is the corresponding basic compound. We must therefore refrain from forming any opinion about the constitution of the vegetable bases, until further investigations shall have furnished us with further grounds upon which we may build a theory of their proper nature.*

We have before remarked that these vegetable alkalis obtain their nitrogen from protein decomposed in the plant. Now, although they contain no ammonia, yet they may very well have been formed from some non-nitrogenous body and ammonia, as orcein, phloridzin, &c., are.

There are a few volatile alkalis, which contain no oxygen, viz.:

Narcotin (Ortigosa), $C^{10} N^3 N$.
Conicin (Ortigosa), $C^{16} N^{16} N$.

Some of these vegetable alkalis have already been imitated by art, and we have reason, therefore, to expect that hereafter further light will be thrown upon their nature.

The following substances, although they are not alkalis, may, I think, be most appropriately mentioned here.

* Since the researches here alluded to were published, the formulæ for the organic alkalis have been called in question by Laurent and others, so that both the constitution and the composition of these bodies may be considered as still (Sept. 1845) in some measure undetermined.—*J.*

Amygdalin, $C^{40}\ H^{27}\ N\ O^{22}$.

When treated with an alkali, this body loses an equi ammonia and takes up two equivalents of water amygdalic acid,

$$C^{40}\ H^{26}\ O^{24} = C^{40}\ H^{27}\ N\ O^{22} + H^2\ O^2 - N$$

This amygdalin, therefore, is a compound of ammoni treated with synaptase, amygdalin is decomposed int acid, oil of bitter almonds, sugar, &c., and it must not be confounded with vegetable alkalis. It is however, that it is produced under circumstances s those which determine the production of these alkal

Caffein, thein, guaranin, all represented by the fo $H^5\ N^2\ O^2$, are not to be considered as compounds o nia any more than

Theobromin, $C^2\ H^5\ N^3\ O^2$.

Asparagin,—$C^8\ H^8\ N^2\ O^6$—must contain ammoni an alkali it is converted into asparagic acid ;—

$$C^8\ H^5\ N\ O^6,$$

and in this change loses ammonia. The elements of of the ammonia, however, are present in some othe

CC. Colouring Substances.

It is an evident proof of the existence of gaps in try, as it at present is, that a class of substances formed and named from their property of being just as if in inorganic chemistry the chromates we nated as a distinct class because they are coloured.

The colouring substances are still but imperfectly Many of them are colourless whilst they are in t but become coloured under the influence of alkalis oxygen of the air. Ammonia can combine with some and purple or blue substances are formed, which co longer any ammonia, but its elements. Others abs gen, and assume a colour through the influence o and soda, for instance :—

Hämatoxylin (Erdmann)	$C^{40}\ H^{17}\ O^{15}$	Becomes red by absor oxygen.

Brazelin* (Preisser)	$C^{36}\,H^{14}\,O^{12}$	Becomes red by the action of potash with absorption of oxygen, and is then converted into
Brazelein (Preisser)	$C^{36}\,H^{14}\,O^{14}$	of a red colour.
Carthamin (Preisser)	$C^{28}\,H^{9}\,O^{5}$	Becomes red by the action of potash and with absorption of oxygen, and is then converted into
Carthamein (Preisser)	$C^{28}\,H^{9}\,O^{7}$	of a red colour.

Santalin, in the colourless state, is unknown

Santalein (Pelletier)	$C^{6}\,H^{5}\,O^{2}$	Red, and may be made colourless through the influence of sulphuretted hydrogen.
Quercitrin (Preisser)	$C^{12}\,H^{15}\,O^{14}$	Becomes yellow in the air, with absorption of oxygen, and produces
Quercitrein (Preisser)	$C^{12}\,H^{15}\,O^{18}$	of a yellow colour†
Spirein (Löwig and Weidmann)	$C^{35}\,H^{8}\,O^{7}$	is of a yellow colour.

These and others contain no nitrogen. They may be developed in all parts of a plant. They exist originally in the plant in an uncoloured state, but they are coloured by the absorption of oxygen and at the same time they undergo a change, which is a simple oxidation

One of the substances which are coloured by the combined influence of ammonia and oxygen, but are colourless themselves, is

Lecanorin (Schunk) $C^{18}\,H^{8}\,O^{8}$.

When this substance is boiled with baryta, it loses 2 equivalents of carbonic acid, and forms orcin, $C^{16}\,H^{8}\,O^{4}$, which in its turn is converted into a fine blue coloured substance called orcein, by the absorption of oxygen and ammonia‡. This change is similar to that effected in phloridzin, when it is converted into phloridzein (p. 811) and in this manner artificially coloured substances are formed which are no doubt similar to those occurring in some flowers

* [illegible]

† [illegible]

‡ [illegible]

Finally, we must notice white indigo, $C^{16}\ H^5\ N\ O$, v
by absorption of oxygen, is converted into the blue ind

$$C^{16}\ H^5\ N\ O^2 + HO,$$

by mere exposure to the air.

This brief enumeration of these substances induces
conclude, that the coloured substances of plants are p
ed by the oxidation of colourless bodies; that, the
these require oxygen to obtain their colour; that thi
gen is absorbed from the air, and that consequentl
objects, such as the petals, if they contain such a colo
body, will more readily become coloured the thinner th

Nothing can be advanced, with even the smallest
of probability, regarding the origin of all these substa
The greater part of them are at present even entirel
known, whilst others have not been analysed either wit
ficient care, or by chemists whose results can be com
trusted. Latterly, scientific men have been much more
pied in exposing organic substances to various influ
and producing from them derived bodies, than in inve
ing what combinations exist in plants. It remains,
theless, a matter of the highest importance to obtain a
ledge of these bodies in the state in which they app
changes in the contents of the cells;—a matter of
importance, in my opinion, than to know the nature of
thaline, and what products it can be made to yield.
chemistry is a science of such an amazing extent, the
study it will certainly not be exclusively directed by a
for utility; but yet a choice must be made, and when
to do so, they ought to prefer to all other substances
which can contribute to explain the operations of N
for Nature ranks above Art.†

* Meyen, Phys. ii., p. 428, has collected a great number of interesti
regarding colouring substances.

† Since the above was written, a considerable amount of labour h
spent upon the colouring substances by various chemists. Mulder h
self investigated and added much to our knowledge of the remarkable
the chrysamminic, aloetinic, and aloe-resinic—obtained by the action
acid upon aloes. But the greatest number of new bodies of this class h
described by Dr. Stenhouse. Of these I subjoin such names and for
have as yet been published:—

But this part of science is still far from forming a certain whole. Here vegetable physiology ought to lend its aid to chemistry, and positively state what she requires the latter to accomplish. Chemistry, in its turn, ought to place the substances of the vegetable kingdom in such conditions as are somewhat similar to those in which they exist in plants.

The discovery of Piria, regarding the separation of salicine into new compounds, may here serve as an example. This discovery is the finest that could now be made in the province of Phyto-Chemistry.

α Orcellic	acid	.....	$C^{18}\ H^{15}\ O^{12}\ HO$	In South American Roccella tinctoria.
α Orcelesic	"	.....	$C^{6}\ H^{8}\ O^{7}\ HO$	
β Orcellic	"	.....	$C^{34}\ H^{17}\ O^{14}\ HO$	In the Cape variety of Roccella tinctoria.
β Orcelesic	"	.....		
Roccellenine	"	.....	$C^{36}\ H^{17}\ O^{13}$	
Erythosic	"	.....	$C^{20}\ H^{10}\ O^{8}\ HO$	From the Roccella Montagnei.
Erythrelesic	"	.....		
Piero Erythrin	"	.....	$C^{34}\ H^{24}\ O^{20}$	
Pseudo-Orcein	"	.....	$C^{10}\ H^{13}\ O^{10}$	
Evernic	"	.....	$C^{34}\ H^{15}\ O^{12}\ HO$	From the Evernia prunastri.
Evernesic	"	.....	$C^{16}\ H^{9}\ O^{7}\ HO$	
Orcin	"	.....	$C^{16}\ H^{11}\ O^{7}$	

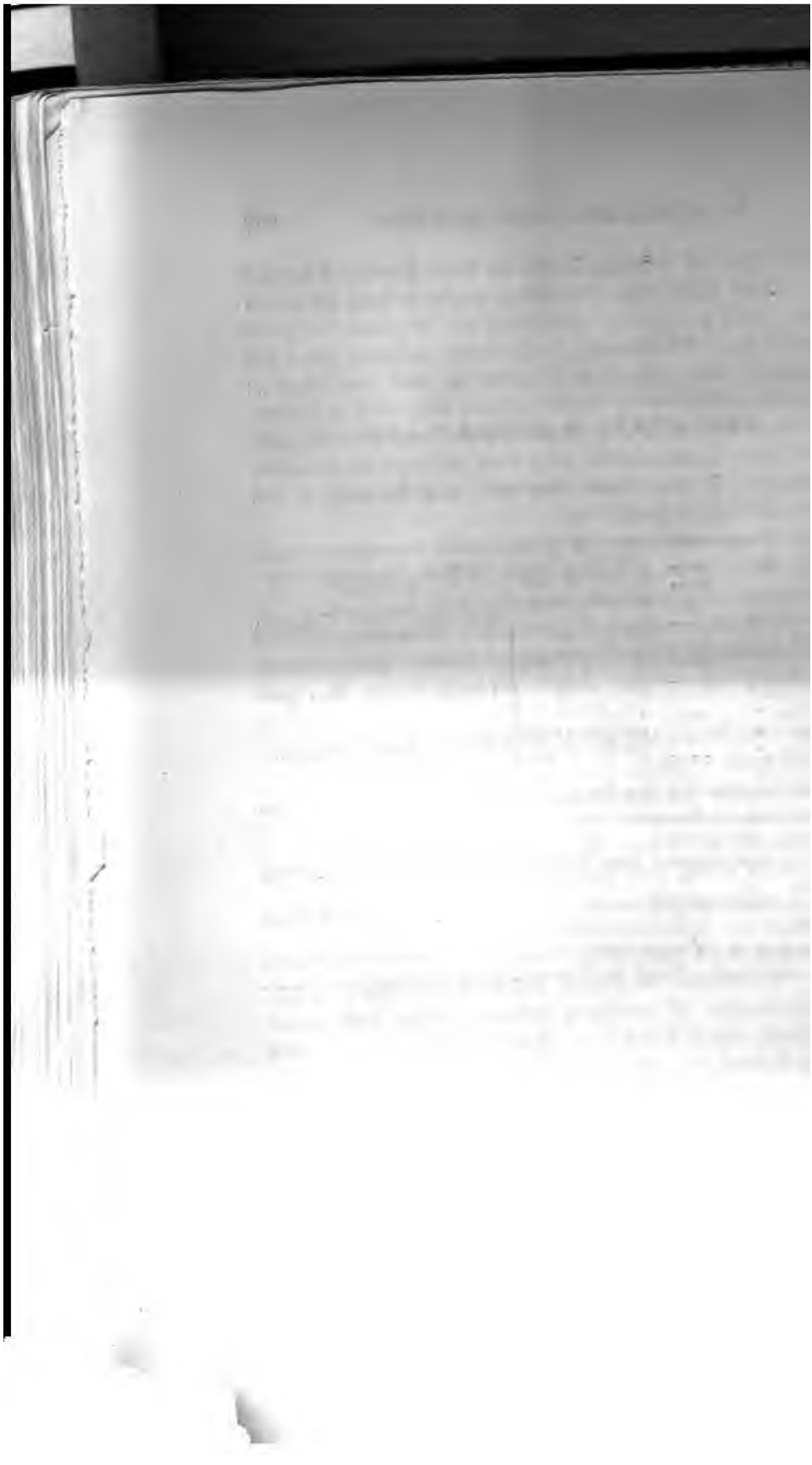
It will be observed that this formula, which is still only empirical, differs from that given for orcin in the text.

Usnic acid = $C^{36}\ H^{17}\ O^{14}$.

This acid is best obtained from the Usnea florida, and from the Cladonia rangeferina.

All these substances give beautiful colours when subjected to the action of hypochlorite of lime and other substances.

The chemistry of these so-called colouring substances will hereafter form a large volume of itself—though as yet few of the materials have been collected. —*J.*



EXPLANATION OF THE PLATES.

FIG. 1. Transverse section of the fourth internode (counting from the top) of a young sprout of Hoya carnosa.

A. Treated with nitric acid, and then with ammonia.

B. Treated with tincture of iodine, and then with sulphuric acid (4 parts of acid of spec. grav. 1.85 and 1 part of water).

The following letters denote in both figures the same parts: —

a. The cuticle disengaged at *a'* by the sulphuric acid.

b. Epidermic cells.

c. Parenchyme of the bark.

d. Bundles of fibres.

e Layer of cambium-cells.

f. Layer of wood and vessels.

g. Milk sap-vessels.

h. Pith.

i. Thick-walled pith-cells.

Fig. 2. Transverse section of the wood and pith of a full-grown internode of Asclepias Syriaca, treated with iodine and sulphuric acid (4 of acid to 1 of water). All those wood-cells show two layers; the exterior, which becomes brown and does not swell up, and the interior, coloured greenish-blue, which swells up.

a. Medullary ray, the cells of which appear green, because the interior blue membrane shines through the exterior brown coloured one; *bb*: punctated vessels, the exterior layer of which is coloured like that of the wood-cells; in the interior is observed a greenish-blue, thin, membraneous layer, with irregular outline; *c* spiral vessel; the spiral is

coloured yellowish green; *d.* a layer of milk sap-ve pith-cells, presenting a great number of round pores.

Fig. 3. Longitudinal section of the pith-cells of t plant, moistened with iodine and sulphuric acid: th have here the appearance of clefts.

Fig. 4. One of the same pith-cells, moistened simp water, which also causes the cleft-formed pores to ap

Fig. 5. Cells of the diachyme of a very young leaf fr interior of the corolla of Sempervivum arboreseens, with iodine and sulphuric acid, and presenting nu round pores.

Fig. 6. Young wood-cells of a young internode of pias Syriaca, treated with iodine and sulphuric acid: diately after the addition of sulphuric acid the cleft- transverse pores are seen, which, after some time, di in consequence of the swelling of the whole.

Fig. 7. Transverse section of the wood-cells and of vessel of the same internode, treated with iodine and ric acid: the wood-cells become blue, as do also the brane-walls of the spiral vessel; the fibre, on the co becomes yellowish-green.

Fig. 8. Transverse section of a leaf of Aloë lingua, with diluted nitric acid. The thickened part of the mic cells (cuticle) is coloured light yellow; the wart which (one is represented at *a*) are studded with little In the cells of the epidermis, stoma, and the exterior the parenchyme, the utriculi interni have become sep the chlorophyll is yellowish-green, the granules are not gular as before the action of the acid. On the surface more interior cells, which contain no chlorophyll, are s points of union, *b b b b*, of the cells, divided by the cu some of these cells a resin globule, *c*, is seen.

Fig. 9. Part of an air-vessel of the peduncle of Mus disiaca.

A. Treated with iodine and sulphuric acid (4 parts 1 of water).

B. Treated with nitric acid and ammonia, by which, i cells, little brown bodies, *a*, are made to appear.

Fig. 10. Parenchyme-cells of a very young leaf of Agave Americana, treated with tolerably diluted nitric acid. The utriculi interni have become distinct; in many cells two kernels (nuclei) are observed, which do not contain those small kernels (nuclei) observed in other cases.

Fig. 11. Transverse section of the parenchyme-cells of Aspidium filix-mas, treated with iodine and sulphuric acid (4 to 1). The wall is greatly swollen, and in the interior exhibits a brown granular ring.

Fig. 12. Transverse section of the epidermis and some of the collenchyme-cells lying under it, of a half-grown internode of Phytolacca decandra.

Fig. 13. The same, after treating with concentrated nitric acid, and then with ammonia: the exterior layer of the epidermic-cells has become yellow, but is otherwise unaltered; the thickened parts of the collenchyme-cells are much swollen, though not coloured yellow.

Fig. 14. Transverse section of the cork-layer and the collenchyme of Opuntia brasiliensis, treated with iodine and sulphuric acid (4 to 1): *a*, cork-cells; *b*, collenchyme-cells, in which more or less distinct concentric layers are visible.

Fig. 15. Transverse section of inner bark fibre-cells, treated with iodine and sulphuric acid, of a full-grown internode of Asclepias Syriaca: they become entirely blue, so that neither in the direction of the surface nor of the interior is another coloured layer to be seen; during the swelling concentric rings show themselves.

Fig. 16. Transverse section of the exterior wood-layer of Pinus sylvestris, treated with iodine and sulphuric acid (4 to 1): *a*, cambium-cells, *b*, full-grown wood-cells.

Fig. 17. Transverse section of the wood-cells of Pinus sylvestris, after having been macerated for 48 hours in concentrated muriatic acid.

Fig. 18. The cells represented in Fig. 16 some time later, after the exterior layer of the wood cells has burst in consequence of the swelling of the interior layer; the exterior layer forms, on some places (*a*), a contracted membrane.

Fig. 19. Longitudinal section of the wood of Taxus baccata,

treated with iodine and sulphuric acid (4 to 1). younger wood-cells, where the colour of the innermo which contains the spiral, is very intense (*a*), the sp disappeared, probably in consequence of the greater s The spots, with oblique cleft-formed pores, on th hand, are still visible and unaltered; they are also c in the outermost layer, which is not attacked by the s acid.

Fig. 20. Wood-cells of Pinus larix, seen on a radi tudinal section; the spots seen from above, treated wit and sulphuric acid (4 to 1).

Fig. 21. The same on a tangential transverse secti the spots which are contained in the outermost ur layer cut through longitudinally.

Fig. 22. Transverse section of the wood of a one- branch of Tilia parvifolia, treated with iodine and s acid (4 to 1). The inner layer of the wood-cells greatly swollen and blueish-green, the external is n len, and brown-yellow; *aa*, medullary rays; *bb*, ves through, the exterior wall of which, containing the s mains brown, while the part containing the spiral is g blue.

Fig. 23. Longitudinal section of the same wood tr the same manner: *a*, wood-cells; *b*, vessel-cell with an s spiral fibre; *c*, two adjoining punctated spiral vessel-c wall joining the two vessel-cells is split longitudir which means the punctated places which are cont the exterior layer appear; *d*, spiral vessel, belongin medullary sheath; the wall is tolerably thick, and b yellow, the spiral blueish-green.

Fig. 24. Longitudinal section of the wood and p full-grown internode of Tilia parvifolia, after havi treated for 48 hours with muriatic acid: *a a*, wood- spiral vessel rolled up from below, in which the spi appears also coloured; *c*, pith-cells; some have shrive let-coloured contents (utriculus internus)

Fig. 25. Transverse section of wood-cells of the san treated with iodine and sulphuric acid (4 to 1). Th

most layer immediately swells very much, while it becomes of a bright blue, and bursts the external layer.

Fig. 26. Pith-cells of a two-year-old branch of the same plant, treated in the same manner. The outermost membrane remains brownish-yellow, the innermost becomes blue, the latter shining through the brown exterior wall makes the cells appear green.

Fig. 27. Transverse section of the parenchyme of a young peduncle of Cycas revoluta, treated with iodine and sulphuric acid (4 to 1). The walls are greatly swollen, and show alternately thinner and thicker places; on the common wall between two cells appears a lighter whitish stripe; where the exterior and interior wall has been cut away, a brownish-yellow coloured irregular interior ring is observed (utriculus internus). *a a* are two cells, of which only the exterior wall is separated, and where, in the remaining part of the wall, small openings are observed. *b* is one of the fibres of inner-bark, which are scattered through the parenchyme, in which three layers, and after the swelling concentric rings, become visible.

Fig. 28. Longitudinal section of the thick-walled parenchyme cells, near to the vessel-bundles in an older peduncle of the same plant. The outermost layer remains dark brown-coloured, the interior shines through with a green colour, except on those places where there are openings, through which the inside plane of the opposite wall appears light blue; at *a a* this under wall is taken away and the opening is seen through.

Fig. 29. The same cells, after digesting for 48 hours in muriatic acid.

Fig. 30. Longitudinal section of very young wood-cells of Clematis vitalba, treated with iodine and sulphuric acid (4 to 1), by which the cleft-formed pores are made apparent.

Fig. 31. Transverse section of the short wood-cells of a full-grown internode of a year-old twig of the same plant. The external sharp-edged layer remains well visible, the internal is greatly swollen white near the external layer, and

blue towards the middle; this layer is bordered by a brow ish ring of unequal thickness.

Fig. 32. Longitudinal section of the same wood-cells, mo ened only with water.

Fig. 33. The same coloured with iodine, and then moist ed with sulphuric acid (4 to 1); the punctated canals app white.

Fig. 34. The same, some time later; the punctated can are no longer visible; the walls run in minute undulation

Fig. 35. Thick-walled short wood-cells of a two-years twig of Clematis vitalba, cut through transversely; conc tric rings are distinctly visible. At *aa*, the punctated tra verse wall of the cell has remained unaltered.

Fig. 36. The same cells treated with iodine and sulphu acid (4 to 1). The outermost layer is coloured dark-brow in the swollen part the same rings as in fig. 35 are appare only more distant from each other; near the opening of t cell the colour is a dark blueish green, the outermost rings coloured yellow. At the beginning of the swelling, traces the small canals are still observable; at a later period, th have disappeared entirely; many cells swell up also so mu that the opening is filled up completely; no internal end ing membrane is observed around the opening.

Fig. 37. Wood-cells of the same plant cut through lon tudinally, after digestion for forty-eight hours in muria acid.

Fig. 38. Longitudinal section of a bundle of inner-b fibre-cells in an interior leaf of the corolla of a very you plant of Agave Americana: after having been treated twenty-six hours with iodine and sulphuric acid, the c tents appear dark-brown, the walls are swollen up, and loured uniformly blue, as well as those of the parenchyr cells.

Fig. 39. Transverse section of an inner-bark bundle o leaf a little older, and situated more to the exterior, of same plant, after treatment for twenty-one hours with same re-agents. The walls of the young cells appear shar defined and brown.

Fig. 40. Transverse section of a group of inner-bark vessels of a full grown leaf of Agave Americana.

A. Coloured brown by tincture of iodine.

B. The same, in dilute sulphuric acid, to which concentrated sulphuric acid was afterwards applied: the walls swell in all directions greatly, their central part becomes blue, the external circumference of the cell and the line limiting the opening remain brown; during the swelling concentric rings become visible.

C. The same, a few minutes later: the opening has entirely disappeared, the blue colour gradually turns brown, and the whole cell becomes at last brown.

D. The same, some minutes later still: the internal mass gradually disappears altogether, leaving only the dark brown outermost membranes of the cells; in a few *aaa*, traces of the internal layers also still remain; on the addition of a fresh quantity of concentrated sulphuric acid, the remaining parts of the cells continue unchanged.

Fig. 41. Section of thick-walled pith-cells of an old twig of Hoya carnosa, immediately after having been moistened with concentrated sulphuric acid.

Fig. 42. The same, some minutes later: *a*, greatly swollen; *b*, part of a cell; the small canals gradually disappear, without leaving behind any traces of an enveloping membrane.

Fig. 43. Longitudinal section of the punctated vessels of Clematis vitalba, treated with iodine and sulphuric acid (4 to 1): *a*, one of the larger punctated vessels cut through longitudinally, so that the points in the brown external small layer, which are cut through, become apparent at *b*; at *d* is seen one of the transverse walls, which originally surrounded the vessel-cells; at *c* are small punctated vessels standing one upon another with oblique ground planes.

Fig. 44. Longitudinal section of the wood from one of the oldest internodes of an annual branch of Vitis vinifera, treated with iodine and sulphuric acid (4 to 1): *aa*, wood-cells, the internal part of which is greatly swollen, so that

the points have disappeared; *b*, a part of a punctated with perforated points; *c*, a striated vessel.

Fig. 45. Spiral fibres of a full-grown leaf of Agave cana in its natural state, moistened simply with water.

Fig. 46. The same spiral fibres, after having remain some time in tolerably concentrated sulphuric acid.

Fig. 47. The same, a little later; the fibres have diss ed entirely, leaving irregular round little balls. On t plication of concentrated sulphuric acid, the fibres a solved immediately, and leave behind the same little b

Fig. 48. The same spiral fibres in a concentrated s of potash; they are greatly swollen, and the border is n

Fig. 49. The same fibres in concentrated nitric acid, rated afterwards with ammonia. The fibres are uni swollen and coloured yellow after the reaction of amm

Fig. 50. Spiral fibres of a very young plant of Agave ricana, after having been treated with tincture of iodi sulphuric acid (4 to 1).

Fig. 51. Spiral fibres of a full-grown leaf, treated same manner.

Fig. 52. Spiral fibres coloured at first green by iodin sulphuric acid; after some hours they have turned bro red.

Fig. 53. Transverse section of the spiral cells of Ma ria pusilla, after having been first treated with concen nitric acid, and then with ammonia.

Fig. 54. The same, seen longitudinally; the spiral is y the membrane of the cell is uncoloured.

Fig. 55. The same spiral cells, digested first in tinct iodine, then placed in sulphuric acid (4 to 1).

Fig. 56. Spiral fibre of the same cells, after the c membrane has been destroyed by the action of sulphuri and the colour of the fibre has changed from brown to

Fig. 57. The same seen transversely.

Fig. 58. The same fibres some minutes later: the gre lour has vanished, a brownish-red colour has appear stead, differing from that which is caused by iodine alo

Fig. 59. A part of a spiral cell of the wood substa

Mamillaria prolifera, digested for twenty-four hours in concentrated muriatic acid.

Fig. 60. Longitudinal section of the ring cell tissue of Opuntia microdasys, treated with iodine and sulphuric acid (4 to 1). The external membrane of the ring-cells, and that of the spiral vessels which lie in the centre, is blue; the rings and the spiral fibre are coloured brown; where the underwall of the ring cells is taken away (*aa*), little openings in the wall are observed, which appear white; at *b* the transmutation of the spiral fibre in a ring is represented.

Fig. 61. The same rings in concentrated sulphuric acid, transversely cut through. They are swollen up irregularly, and the opening becomes smaller the longer the action is continued. In one it has disappeared altogether, and the ring has become extremely thin and transparent.

Fig. 62. The same rings thus acted on with sulphuric acid and treated afterwards with tincture of iodine: the external border is darker coloured than the rest; in some, concentr rings are observed.

Fig. 63. One of the same rings treated first with concentrated nitric acid, and then with ammonia.

Fig. 64. One of the same rings first coloured brown by iodine, and treated subsequently with dilute sulphuric acid, to which concentrated sulphuric acid has been slowly added.

Fig. 65. Transverse section of the elongated cells on the end of the vessel-bundle of Opuntia brasiliensis, treated with iodine and sulphuric acid (4 to 1), in which the rings of the ring cells in the centre remain brown-coloured.

Fig. 66. A part of a milk-vessel from the centre of the bark parenchyme of Euphorbia caput-medusæ, on the spot where it divides into two branches; *aaa* points of junction of the cells.

Fig. 67. A part of the preceding, treated with iodine and sulphuric acid (4 to 1): *a*, the milk-sap vessel, dark blue coloured, and surrounded by a very thin brown layer; *bb*, the border, which appears somewhat rough; *cc*, cells, of which the upper and side walls are taken off in order to show the pores.

Fig. 68. Transverse section of the same. The milk-sap

vessel is swollen so much towards the interior, that trace of the hollow space is to be seen ; the swelling to the exterior is prevented by the surrounding brown co thin membrane. The blue colour is most intense in th tre, and diminishes very much near the surrounding brane ; the section of the milk-sap vessel of a round lies in the centre of the surrounding cells, the walls of have become expanded. By this means the opening th which the milk-sap vessel extends has become wider, s between this and the walls of the cells an opening i tinguished. Everywhere, where the wall is simple, num openings are observed. In one cell, of 0.037 of a mille in diameter, the number of these little holes amount between 45 and 50.

Fig. 69. Transverse section of the uncoloured part very young leaf of Agave Americana, at the place whe leaves are still joined together, treated with iodine an phuric acid (4 to 1). The cuticle has detached itsel remains brown-coloured ; the walls of the epidermis cel pear blue, their contents brown ; the walls of the parenc cells are much swollen and uniformly blue-coloured ; th tents brown. It is a hundred times magnified.

Fig. 70. A small part of the same, with the epidermi the detached cuticle, three hundred times magnified.

Fig. 71. Cuticle of the uncoloured part of a very y leaf of Agave Americana, disengaged by sulphuric acid.

Fig. 72. Transverse section of the epidermis of a grown leaf of Agave Americana, treated with tincture of i and sulphuric acid. The thickened part of the cells (cu remains unaltered, even after having been treated a time with concentrated sulphuric acid ; the thin-walled on the contrary, is immediately turned violet-blue after th tion of the sulphuric acid, as well as the parenchyme At *aa*, the section passes just through the axis of the and through that of the cuniform hollows ; at *b*, the thicker and has passed along the exterior wall. The d colour of the wall and of the thickened part of the walls is wholly due to the greater thickness of these par

Fig. 73. Transverse section of the external layer of a young peduncle of Cycas revoluta close to the stem, treated with iodine and sulphuric acid (4 to 1): *a*, the greenish yellow thin external layer, appearing, however, only on one place and wanting elsewhere; *b*, the epidermis cells, the external layer (cuticle) of which remains brownish yellow also below; where it comes in contact with the thick matted inner bark or bast, the interior blue layer shines through, giving a green tinge; *c*, a layer of bast-cells composed of three layers, one brown, another lead-grey, and other brownish-yellow coloured.

Fig. 74. Transverse section of the epidermis and the outermost parenchyme cells of a leaf of Phormium tenax, close to its base, treated with iodine and sulphuric acid (4 to 1). The parenchyme cells are turned by these re-agents entirely blue, the external thickened layer of the epidermis cells (cuticle) remains yellow, and also the prolongation of the same, which like a sheath surrounds the epidermis cell, which has become blue. On many places the epidermis cells appear green, *aa*, in consequence of the interior blue membrane shining through the yellowish-brown exterior.

Fig. 75. Cuticle of Opuntia microdasys, coloured by iodine and separated from the epidermis cells by sulphuric acid (4 to 1), by means of which the thick-walled hairs remain fixed on it.

Fig. 76. Horn-like albumen of Alstroemeria aurea, from seed which has reached only half its full size. The walls are of uniform thickness, and not a trace of small canals is observed; all the cells are filled with a fine granular substance.

Fig. 77. The same from seed a little older. The walls have become thicker, and the canals open with wide mouths in the interior hollows of the cells; *a*, a cell filled with a fine granular white substance, which is not soluble in ether; *b*, a cell, of which the under wall is wanting, so that the openings of the canals are seen.

Fig. 78. The same from a nearly full grown seed with white albumen; *a* and *b* as in the preceding figure.

Fig. 79. The same, from a fully-grown and dried seed, the albumen of which was brown; *aa*, cells filled with fat-globules.

2. Contents, of a cellular appearance.

3. Cell in the nucleated globule enclosed by a p membrane, showing a clear contents.

4. Nucleus of this cell.

Fig. 196. Nucleated globule of the ganglia gass cow (150 times).

1. A nerve fibre.

2. Sheath.

3. A part of the surface, deprived of its sheath.

Fig. 197. Transverse section, across the greatest d of a nucleated globule of a dried ganglia gasseri o after the addition of water and dilute acetic acid (41

1. Sheath, distinct outline.

2. Cell enclosed in the nucleated globule (this appear cut through, but lies very superficially).

d. A thin layer of shapeless blastema, elastic.

e. Fibres of the skin.

Fig. 87. Epithelium of the abdominal membrane of a cow, obtained from the fresh membrane by scraping with a scalpel (410 times magnified).

1. A cell with nucleus.

b. The same obtained on another occasion. All the cells are provided with nuclei.

Fig. 88. The same epithelium, after the addition of acetic acid (410 times magnified).

Fig. 89. Epithelium from the interior of the human mouth, carefully obtained from the inside of the cheek (410 times).

1.1. Kernel nucleus.

2. Fine granules, spread especially round the nucleus.

Fig. 90. The same, kept for six hours in a saturated solution of potash (410 times magnified).

a. At the commencement of the action of the solution.

1. The nucleus.

b. By continued action, the nucleus begins to be dissolved.

c. By still further action.

1. The nucleus completely granular.

d. After the action of the solution is complete.

Fig. 91. *a*, *b*. Epidermis of the thigh (dried with the skin), transverse section, kept for seven hours in potash, and water then added (410 times magnified).

a. Cells of the external layers.

b. A cell of the central layer.

c. Cells of the thickened epidermis of the tops of the fingers, treated in like manner.

Fig. 92. Small plates of the epidermis of the arm, obtained by scraping, kept for eight hours in concentrated acetic acid, (410 times magnified).

Fig. 93. Cylindrical epithelium of the intestines of a rabbit (according to Henle).

a. Cuniform cells.

b. Intercellular substance.

Fig. 94. Ciliated epithelium, obtained by scraping the tongue of a frog (410 times magnified).

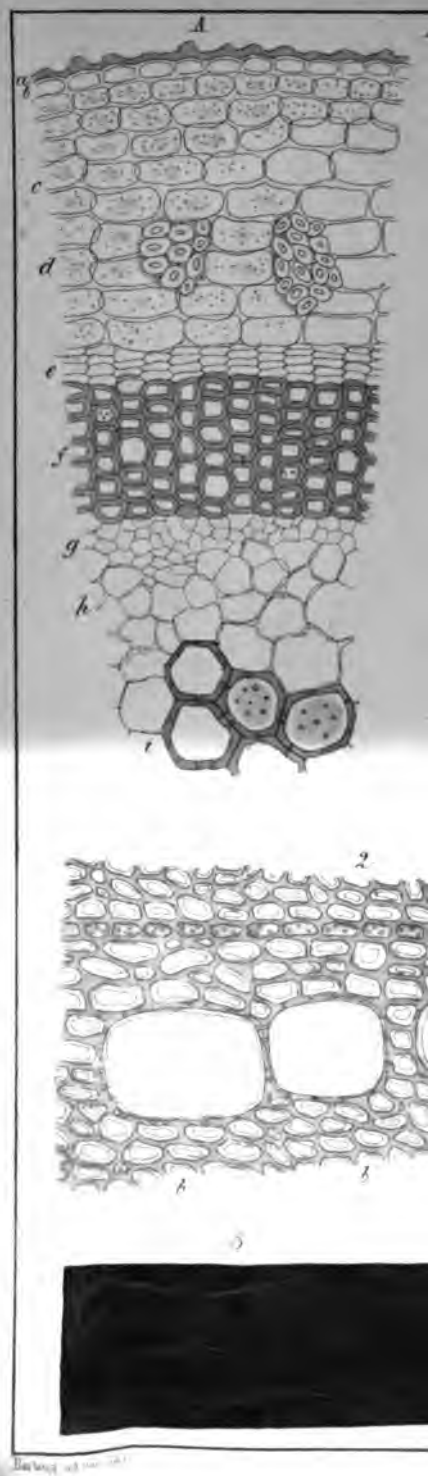

A
a
c
d
e
f
g
h
i
2
b
b
3

Fig. 102. Transverse section of the striped substance (120 times).

1. Whalebone canals.
2. Concentric whalebone plates.

Fig. 103. The same, of a whalebone canal, with the little plates belonging to it, more highly magnified (410 times).

1. Whalebone canal.
2. Concentric whalebone plate.
3. Dark points (hollow?)

Fig. 104. Longitudinal section of the striped substance (50 times).

1. Whalebone canal.
2. Fat cells in the same.
3. Whalebone canals cut through.
4. Concentric plates.

Fig. 105. The same, of a whalebone canal, with the surrounding plates (410 times).

1. Concentric plates (seen on the section).
2. Dark spots (hollow?)
3. Concentric plates cut through obliquely.
4. Fat cell.
5. Fine black granular substance.

Fig. 106. A thicker transverse section of whalebone, kept for twenty-four hours in potash solution, and water then added (410 times).

a. Joined cells.

b. Isolated whalebone cells, obtained by pressing and further addition of water.

1. Granular contents (remainder of a nucleus?)

Fig. 107. A very thin transverse section of the striped substance, kept for forty-eight hours in a concentrated solution of potash, then water added (410 times). An isolated whalebone canal with all its concentric plates.

Fig. 108. The same, obtained in the same manner. The little plates become isolated by pressure and rubbing, then become folded, and break off (410 times).

1. A folded plate.

Fig. 116. Jointed tissue between the muscles of the thigh of a full-grown man (410 times.)

a. Connected bundles.

1. A folded bundle.

b. An isolated bundle with distinct primitive fibres.

Fig. 117. Elastic fibres of the same, remaining after the action of potash during four hours and addition of water, by which the thread-fibres (gelatine-producing fibres) become dissolved (410 times).

Fig. 118. Jointed tissue, beneath the fascia lata, kept for five hours in a concentrated potash solution (410 times).

1. Apparent openings, filled with a granular substance.

2. Fibres, by which these are surrounded.

Fig. 119. Elastic fibres of the skin of the thigh of a full-grown man, kept for four hours in dilute acetic acid (410 times).

a. Surface (near the epidermis) with thin fibres.

b. The middle part (is awanting.)

c. Deepest part with thicker fibres, which become gradually thinner towards the surface.

Fig. 120. Transverse section of the dried tendon of the musculus semi-tendinosus, after the addition of water (50 times).

1. Secondary bundles.

2. Detached jointed tissue between the secondary bundles.

3. Section of a blood-vessel of the same.

4. Fat tissue, in the same.

Fig. 121. Longitudinal section of the same tendon, after addition of dilute acetic acid (410 times).

1. Parallel primitive tendon bundles, which have become perfectly gelatinous.

2. Elastic fibres.

Fig. 122. The same, obtained by adding acetic acid to a thicker transverse section, by which the bundles become folded (410 times).

1. Parallel primitive tendon bundles, which have become gelatinous.

2. Elastic fibres.

Fig. 123. The same, obtained from a thinner transverse section.

1. Parallel gelatinous tendon-bundles.
2. Elastic fibres.

Fig. 124. 1. A primitive tendon-bundle of the same tendon in its fresh state (410 times).

2. Primitive fibres, isolated by pins.

Fig. 125. Primitive fibres of the ligamentum sacro-tuberosum,—kept for fifty hours in a saturated solution of potash, without adding water (410 times).

Fig. 126. Longitudinal section of the ligamentum nuchæ vel colli of a cow, boiled in acetic acid, and dried (410 times).

Fig. 127. A single fibre of the same, fresh (410 times).

Fig. 128. Fibres of the same, kept for twenty-four hours in a potash solution, and water added (410 times).

Fig. 129. Transverse section of the same, dried, treated with concentrated acetic acid (410 times).

Fig. 130. Fibres of the same, kept for many days in potash solution, and water added.

Fig. 131. The tissue *jaune* of a man, dried (410 times).

a. Section, parallel with the surface, treated with acetic acid.

1. Elastic fibres.
2. Gelatinous, swollen gelatine-producing fibres.

b. Transverse section, treated with acetic acid.

1. Elastic fibres.
2. Gelatine-producing fibres, rendered gelatinous.

Fig. 132. Fibres of the vocal chord, treated with acetic acid (410 times).

Fig. 133. Rib-cartilage of a body twenty-two years old. Transverse section, taken near the surface (120 times).

1. More remote from the surface.
2. From the surface of the cartilage.
3. Intercellular substance.
4. Cartilage bodies.

Fig. 134. The same, near the centre (120 times).

1. Cartilage bodies with two cells.
2. Cartilage bodies, with from two to four cells in one line

3. Granular intercellular substance.

4. Fibrous intercellular substance of the asbestus-like ring.

5. Fat globules in the intercellular substance.

Fig. 135. The same (410 times magnified).

a Very small cartilage bodies, near the surface of the cartilage.

b. A rounder cartilage body, from the cartilage of another subject.

1. A nucleus, without cells, in the cartilage body.

2. Cells with nuclei.

3. Nucleus transformed partly into fat.

c. Cartilage bodies, including an extraordinary quantity of fat.

1. A single fat globule in the cartilage body, not inclosed in a cell.

2. Very large fat bodies contained in cells.

3. Granular intercellular substance.

d. The same (from the asbestus-like ring), freed from fat by repeated extractions with ether (410 times).

1. Cells.

2. Membranes of the fat bodies.

3. Fibres of the asbestus-like ring.

Fig. 136. Three transverse sections of ripe cartilages (natural size).

a. Surface of the cartilage.

b. Transverse section.

1. Soft concentric layer, looking like asbestus.

Fig. 137. Cartilage body, swimming in sulphuric acid, obtained by keeping a fine section of rib-cartilage for six hours in sulphuric acid (410 times).

Fig. 138. Intervertebral-cartilage of a full-grown man

a. The solid tissue, separated by pins.

b. The soft central tissue.

Fig. 139. The soft central part of the intervertebral cartilage of a full-grown fœtus, after the addition of water. (410 times).

a Groups of cells, with nucleus and nucleolus in every cell

1 A separate nucleus

b. Shapeless blastema between the groups.

Fig. 140. Fine oblique section (in the direction fibres) of the dried intervertebral cartilage of a full- man (410 times).

1. Cartilage fibres.
2. An oblong cell.
3. A prolonged nucleus.
4. A nucleus fibre.

Fig. 141. Transverse section of the dried elastic e tilage, with the interior layers of the skin, treated w lute acetic acid (120 times magnified).

1. Elastic fibres of the skin.
2. Transition-state between skin and cartilage, with between the elastic fibres.
3. Elastic cartilage tissue.
4. Elastic fibres between the cartilage bodies.
5. Nearly invisible cartilage bodies in the thinner p the section.
6. Cartilage bodies covered by elastic fibres.

Fig. 142. Transverse section of the dried elastic e tilage (410 times).

1. Elastic fibres.
2. Cartilage bodies with cells and nuclei.
3. Fat bodies.

Fig. 143. Transverse section of the dried ear-car kept for 5 hours in a concentrated potash solution, and water added (410 times).

1. Open spaces occupied by the cartilage cells, before solution.
2. Fine net of elastic fibres.

Fig. 144. Part of a thin plate of a transverse section human thigh bone, placed on Venetian turpentine times).

1. Bone bodies.
2. Rays of the bone bodies.

Fig. 145. A thin plate of the human *os pubis* obtain rubbing, placed on Venetian turpentine (410 times).

1. Large bone bodies.
2. Granular intercellular substance.

3. Wide rays of the bone bodies easily distinguishable as little canals.

Fig. 146. Transverse section of the human thigh bone, treated with muriatic acid (50 times).

1, 2. Medullary canals, near the surface of the bone.

3, 4. Medullary canals situated deeper in the bone.

5. Transverse medullary canals connecting the longitudinal.

6. Bone plates parallel to the surface with interlying bone bodies.

7. Bone plates concentric round the medullary canals, likewise with bone bodies.

Fig. 147. The same, a medullary canal with its concentric bone plates. (140 times).

1.1.1. Bone bodies.

2. Bone plates.

3. Medullary canals.

Fig. 148. The same, longitudinal section (410 times magnified).

1. Bone bodies.

2. Bone plates.

3. Bodies (nuclei) in the bone cavities.

Fig. 149. The same (25 times magnified).

1. Longitudinal medullary canals.

2. Transverse medullary canals. The bone plates and cavities of the bone are still in some degree observable as little spots between the medullary canals, *a*, thus magnified.

Fig. 150. The same (410 times) kept for 5½ hours in a concentrated potash solution and washed with water.

1. Bone cavities with nuclei.

2. All containing a nucleus in one of the cavities of the bone.

Fig. 151. Fat cells of the face of a rather lean man (410 times).

1. Fat cells.

2. Granular fibrous tissue between the cells.

Fig. 152. Fat cells of a sheep (120 times), floating in concentrated acetic acid.

Fig. 153. Membranes of the fat cells of a young pig extracted with ether (410 times).

1. A part of the membrane of a
covered by anything, and on whic
can be seen.

Fig. 154. Transverse section of th
sus treated with dilute acetic acid

1. Primitive bundles (drawn alo
2. Perimysium.

Fig 155. The same (410 times r

1. Primitive bundles, in which
tive fibres are observable.
2. Nuclei, placed in the sarcolem

Fig. 156. Transverse section of th
meagre frog, treated with dilute ac

1. Primitive bundles (drawn alo
a. Smaller bundles.
2. Perimysium.
3. Sinew-branch cut through.

Fig. 157. The same (410 times).

a. Smaller bundles.
1. Nuclei placed in the primitive
2. Primitive fibres.
3. Muscle substance between the
4. Hair vessel.

Fig. 158. Oblique longitudinal se
dle of the dried muscle of a frog (
of tincture of iodine.

1. Thicker part showing distinctl
2 Thinner part showing little gr

Fig. 159. Primitive bundle of th
kept for 3 hours in concentrated ac

1. Sarcolemma.
2. Nuclei placed in the primitive
ferent focus.
3. Primitive fibres.
4. Small transverse stripes.

Fig. 160. *a*. Primitive bundle of
for 5 hours in a concentrated potas

1. Nuclei.

b. After the beginning of the act

1. Nuclei.

Fig. 161. The same kept for 24 hours in a concentrated potash solution.

1. Primitive bundles divided into transverse hexagonal parts (410 times).

2. Primitive fibres (410 times).

Fig. 162. Elastic fibres of the deep layer of the involuntary muscles of the gullet of a cow, obtained by digestion for 34 hours with potash and addition of water, by which the other fibres are dissolved. (410 times).

Fig. 163. Elastic fibres, spread between the muscle fibres occurring in the circular fibrous membrane of the human aorta, obtained in the same manner as the preceding (410 times).

1. Fine granules of the muscle fibres, not yet dissolved.

Fig. 164. Involuntary muscle fibres of tape-worm in the colon of a full grown man (410 times).

a. Isolated fibres.

b. Seen in mass.

c. After the action of acetic acid.

1. Nuclei.

2. Elastic fibres.

Fig. 165. Transverse section of the membranes of the dried human aorta, kept for four hours in concentrated acetic acid* (30 times magnified).

1. Tunica adventitia.

2. Tunica elastica.

3. Tunica fibrosa-circularis (elastico-muscularis).

4. Tunica fibrosa-longitudinalis.

5. Tunica striata.

Fig. 166. The same, a transverse section of the fibrosa circularis (120 times magnified).

1. Elastic plates, seen on the section.

2. Muscular fibres (become transparent) and fine elastic fibres between the plates.

Fig. 167. The same (410 times magnified).

* That mentioned in the text has been treated only for a few minutes with acetic acid, and the muscle fibres remain more visible. By keeping longer in acetic acid, however, the elastic tissue appears much more distinct.

1. Elastic plates seen on the section.

2. Muscular fibres (become transparent) and elastic, thinn fibres, most of them cut through transversally.

Fig. 168. The same, net of elastic fibres of the tuni elastica of the aorta seen on the surface (410 times). Th transverse section of the same is seen in fig. 165, 2.

Fig. 169. The same net of elastic fibres, representing on of the exterior elastic plates of the tunica fibrosa-circulari of the aorta, seen on the surface (410 times). The transvers section seen in fig. 165, 3).

Fig. 170. Striped membrane of the fresh carotid artery o a cow, seen on the surface (410 times).

Fig. 171. Muscular fibres of the articular fibrous membrane of the aorta of a young sheep (410 times).

a. Moistened with water only.

1. Exceedingly isolated fibres.

b. After treatment with acetic acid.

Fig. 172. Epithelium of the aorta of a cow, obtained by scraping (410 times magnified).

1. Epithelium plates.

2. Nuclei, with two or three nucleoli.

Fig. 173. Longitudinal section of the membrane of the dried vena azygos treated with acetic acid (410 times). The section was obtained from a vein dried round a soft cylindrical piece of wood.

a. Elastic plates.

1. External.

2. Internal.

b. Jointed tissue become gelatinous.

1. External layers.

2. Internal layers.

Fig. 174. Transverse section of the internal part of the membrane of the dried vena jugularis of a cow (120 times).

a. Elastic plates.

1. Plates situated more externally.

2. Plates situated more internally.

b. Jointed tissue become gelatinous.

1. Internal layers.

2. External layers.

Fig. 175. The same; a small part of the transverse section of one of the external elastic plates of the jugular vein (410 times) (compare fig 174, *a*, 1).

Fig. 176. Elastic plates of the jugular vein of the cow, seen on the surface, obtained by keeping somewhat thicker transverse sections for four hours in concentrated acetic acid, and pressing them between two glass plates, by which the transverse section becomes folded (410 times).

a. External plates.

b. More towards the centre.

c. Still more towards the centre.

1. Openings.

d. Near the striped membrane.

Fig. 177. Jointed tissue between the elastic plates of the fresh jugular vein (410 times).

Fig. 178. A plate of the striped membrane of the subclavian vein of the cow, kept for sixteen hours in a solution of caustic potash and water added; it becomes detached from the other wall of the vein (410 times magnified).

1. An opening.

Fig. 179. Transverse section of the dried sciatic nerve of man, treated with dilute acetic acid (25 times).

1. Secondary bundles.

2. Jointed tissue.

3. Fat tissue in the same.

4. Sheath round every secondary bundle (properly neurilema).

5. An opening, out of which a secondary bundle has fallen.

Fig. 180. The same, one of the smallest secondary bundles (120 times).

1. Sheath round the bundles.

2. Primitive bundles with their primitive fibres.

3. Transparent stripes by which these are separated from one another.

Fig. 181. Separated primitive fibres, cut through transversally (410 times).

Fig. 182. Nerve fibres of the tenth pair of the spinal marrow of the frog, two days old (410 times).

b. Two contiguous fibres with g

1. Cylindrical axis.

2. A fibre with more uniform c

Fig. 183. Fresh fibres of the ten
a frog, kept for half an hour in co
(410 times).

Fig. 184. The same kept for an
tic acid (410 times).

1. Spiral-like twisted cylindrica

Fig. 185. The same kept for tw
centrated potash solution and trea
only fat and soap globules remain

Fig. 186. *a*. Nerve fibres of the
marrow of a frog, kept two days,
times).

b. The same kept for two hours i

Fig. 187. Sympathetic nerve f
branch of the eighth pair of the
(410 times).

a. In fresh state.

b. Kept for an hour in concentr

c. Kept for an hour in concentra

Fig. 188. Transverse section of
man treated with dilute acetic aci

1. Secondary nerve bundles.

2. Jointed tissue.

3. Sheath of the secondary bun

4. Sections of vessels filled with

5. Fat tissue.

Fig. 189. 1. The same, one of th
treated with acetic acid (120 times

1. Sheaths of the primitive bun

2. Sheaths round the secondary

Fig. 189. The same, part of
times).

2. Envelopes of the primitive f
of dilute acetic acid.

3. Contents of the primitive fib

4. Thicker nerve-fibre.

5. Sheath of a secondary bundle.

6. Sheath of a primitive bundle.

Fig. 190. Nerve fibres of the white substance of the brain of a cow, kept 72 hours (410 times magnified).

a. Thin nerve fibres of the external layer of the cornu-Ammonis.

b. Nerve fibres of the hemispheres.

1. A thicker fibre.

c. Thick nerve fibres of the corpora pyramidalia.

Fig. 191. *a*. Nucleated globules of the cortical substance of the hemispheres of the brain of a cow, kept 24 hours (410 times).

1. Granular substance between the nucleated globules.

b. A nucleated globule, more highly magnified (930 times).

Fig. 192. *a*. Globules of a granular nature, and a nucleated globule, seen in the gray substance of the cornu-Ammonis (410 times).

b. Clear smooth globules.

Fig. 193. Nucleated globules of the cerebellum of a cow, kept 24 hours (410 times).

1. One elongated into a pear shape.

2. One spherical.

3. One with two prolongations (nerve fibres?)

4. Smaller bodies occurring interspersed among the nucleated globules.

Fig. 194. Globuli nucleati and nerve fibres of the ganglia gasseri of a cow, 24 hours old (150 times).

1. Nucleated globules.

2. Cell, enclosed in the nucleated globules.

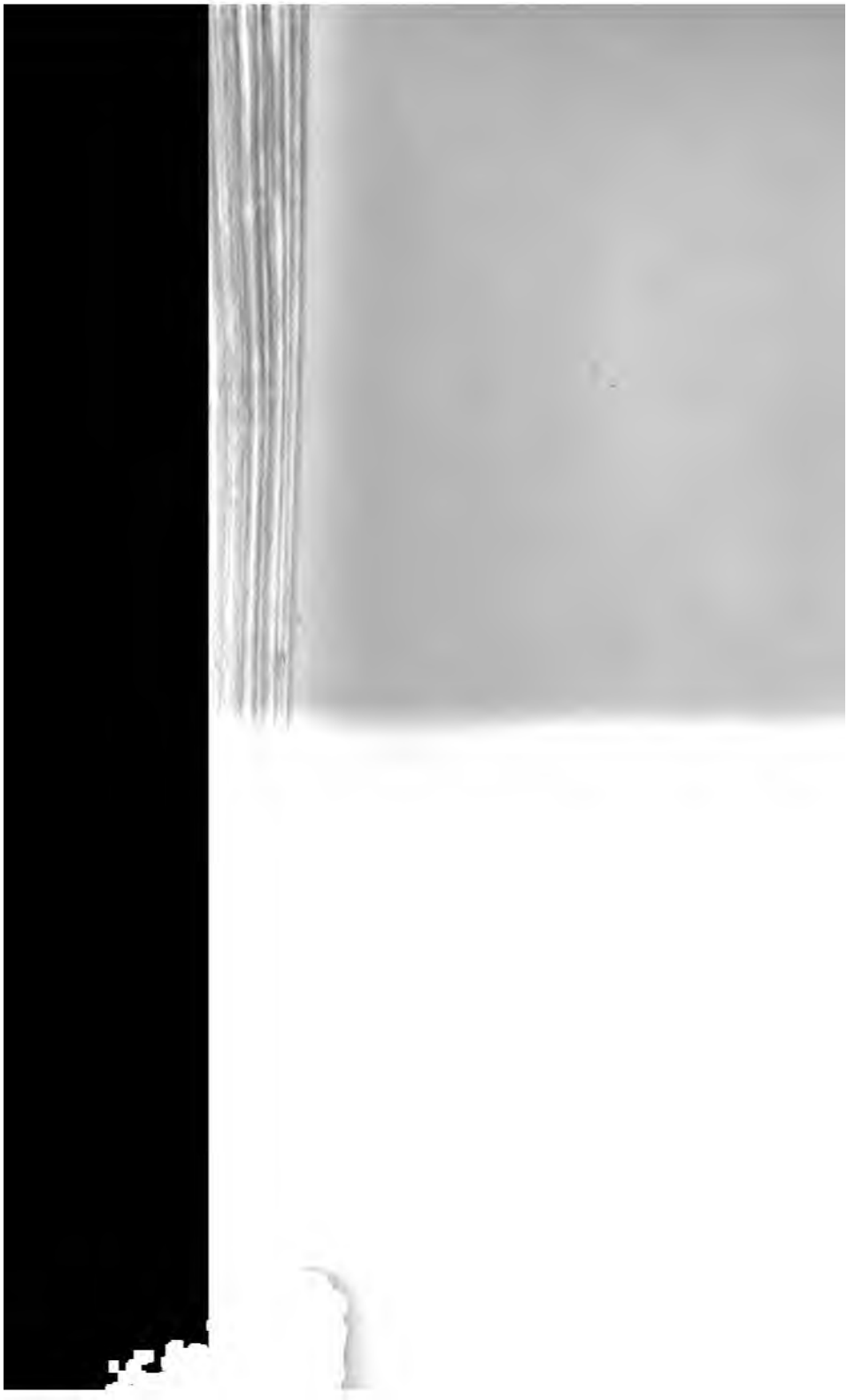
3. Nucleus present in this cell.

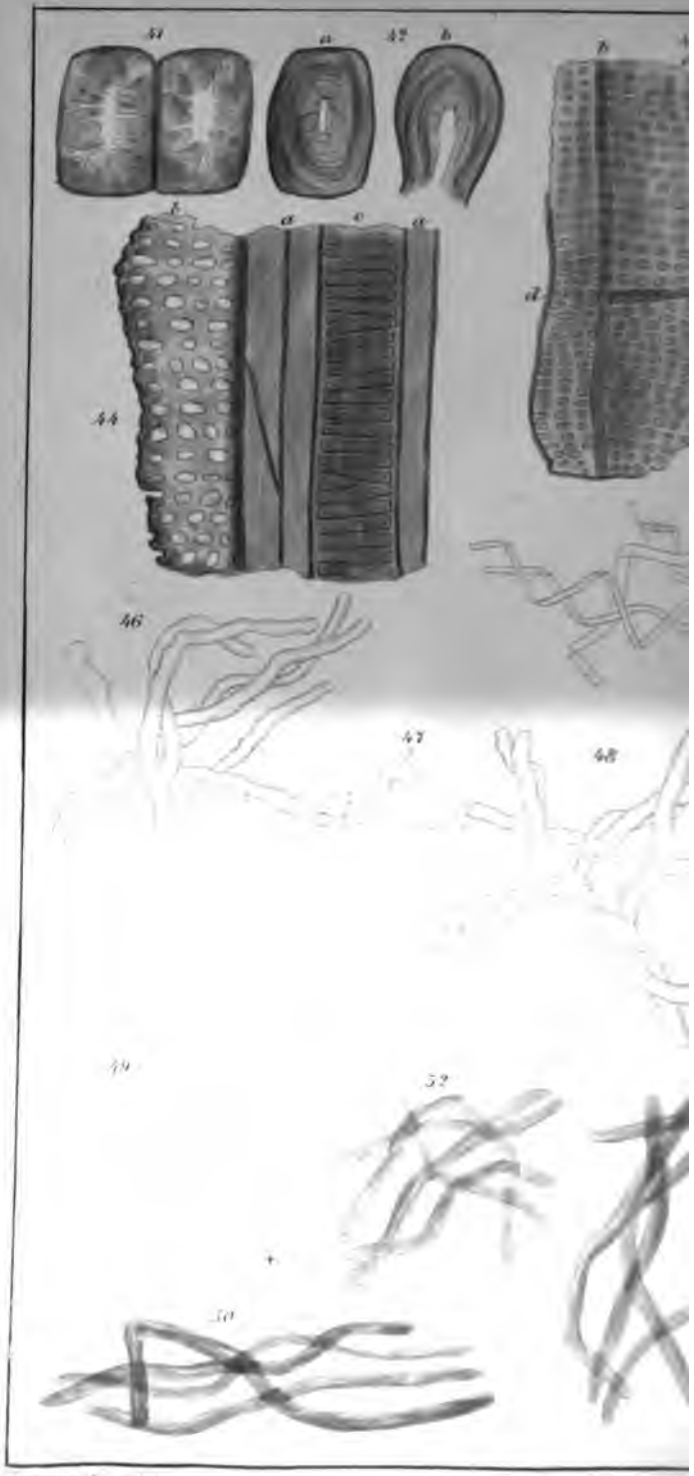
4. Sheath of the nucleated globule, which has been taken away by the two first globules.

5. Nerve fibres.

Fig. 195. Nucleated globules of the ganglia gasseri of a cow treated with acetic acid (410 times).

1. Sheath.

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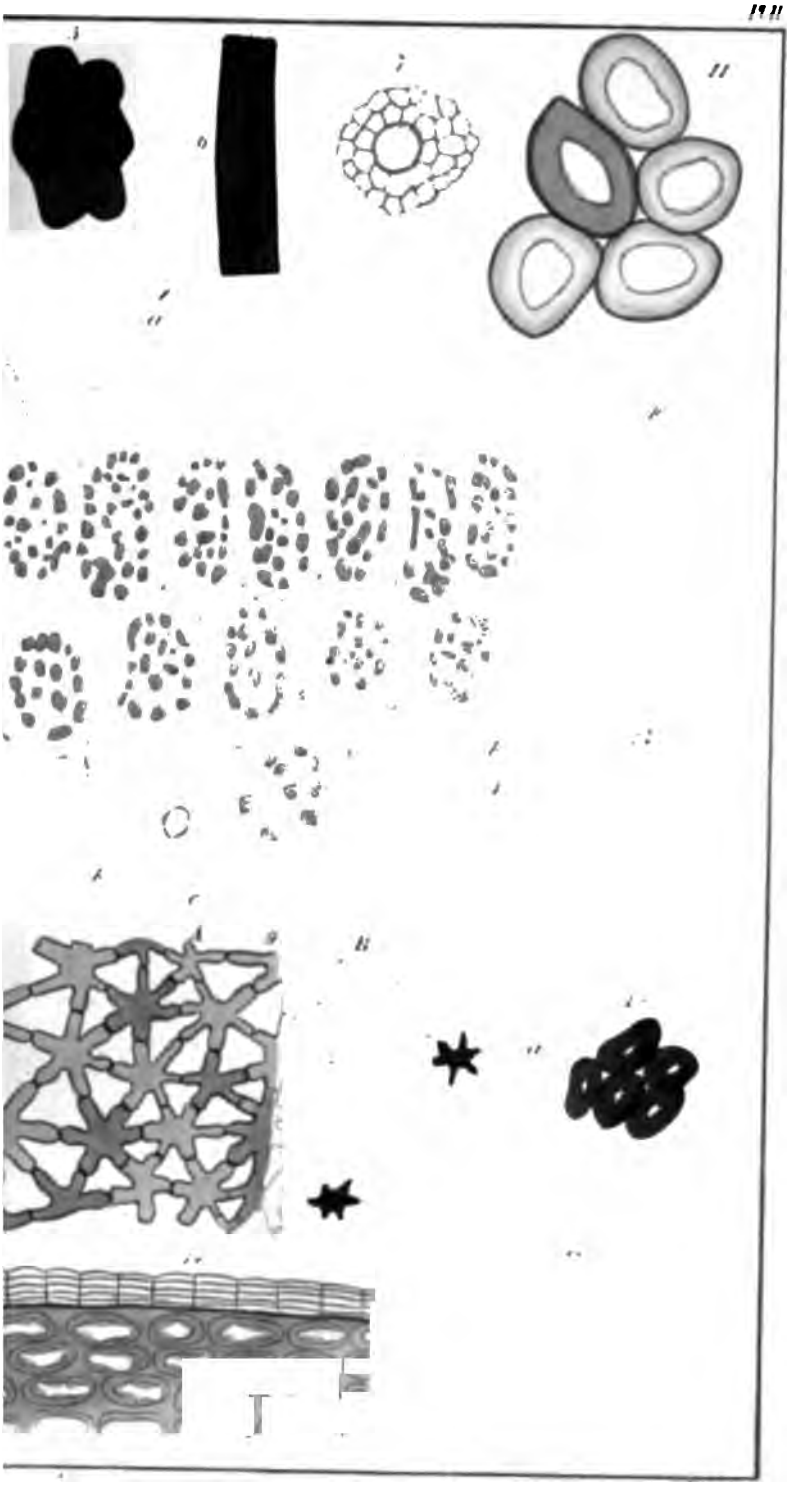

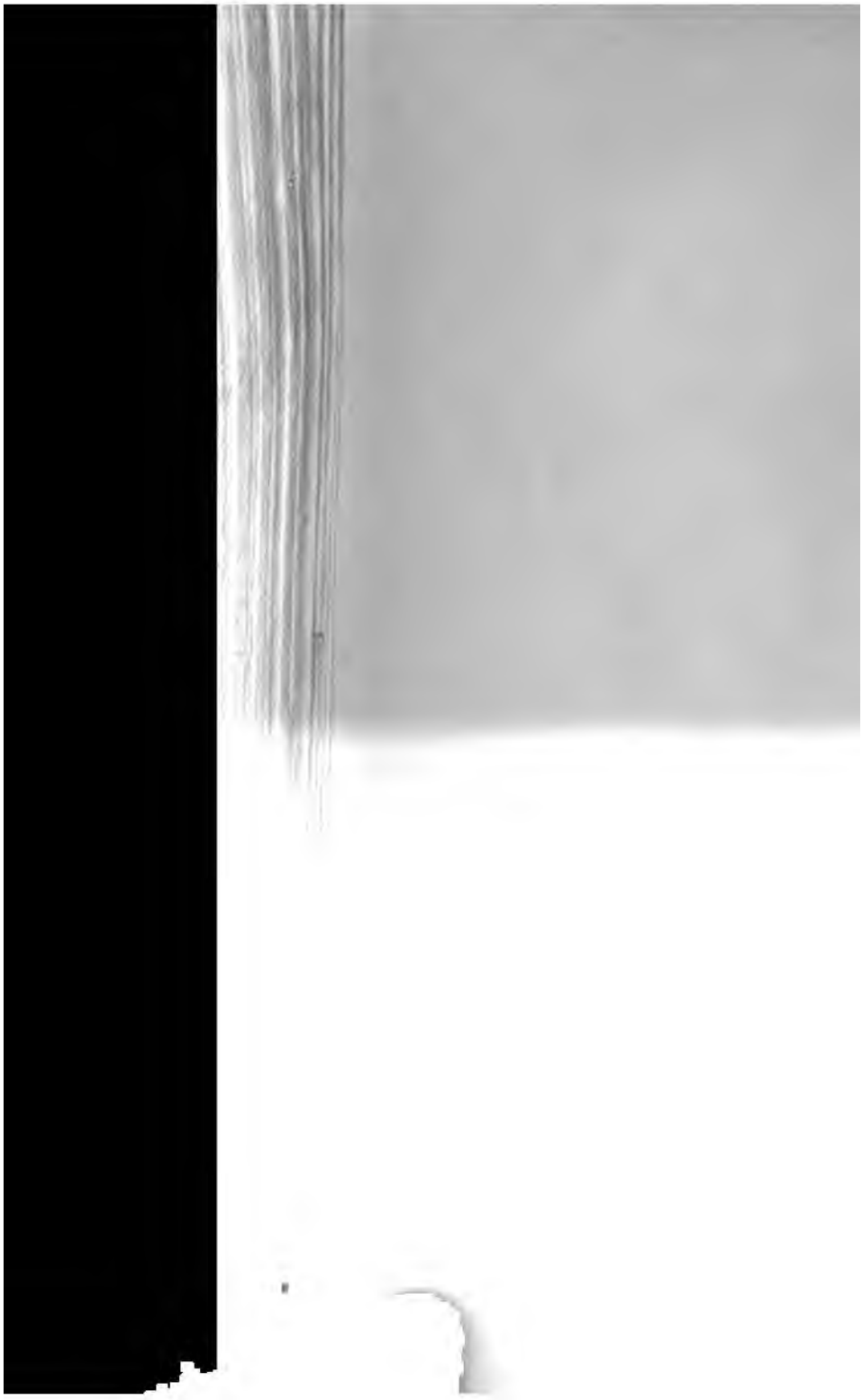

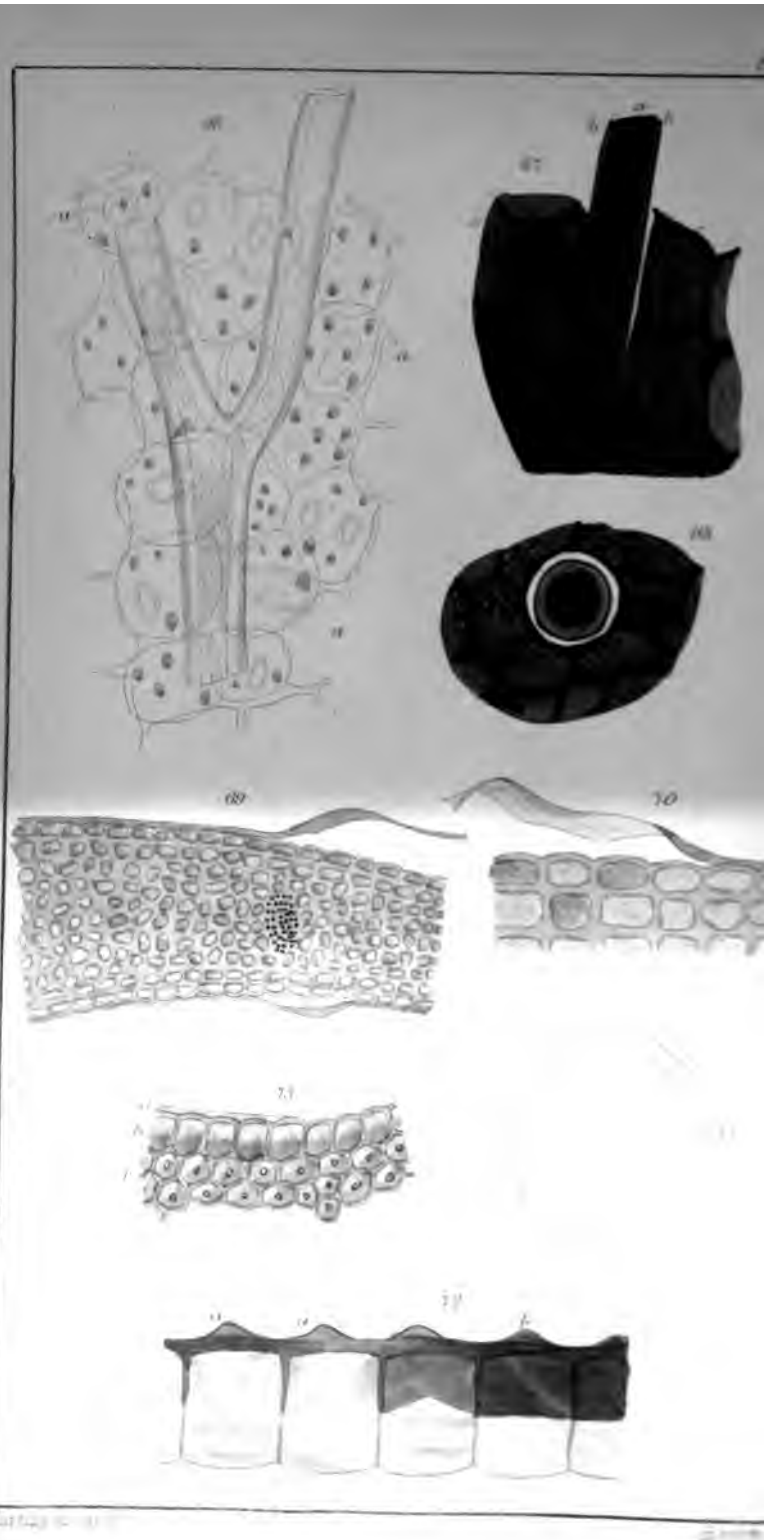

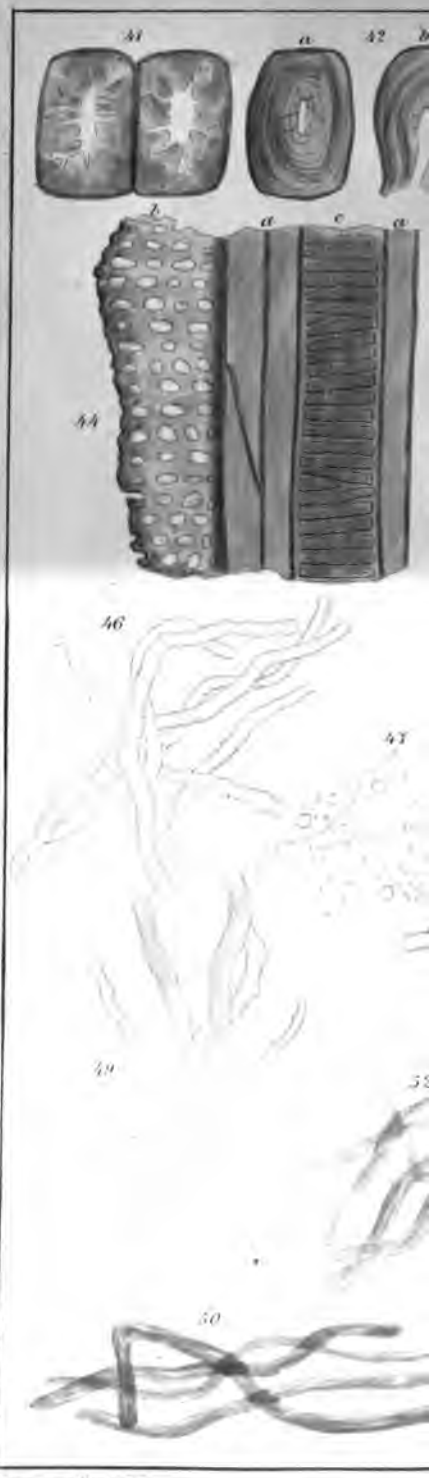
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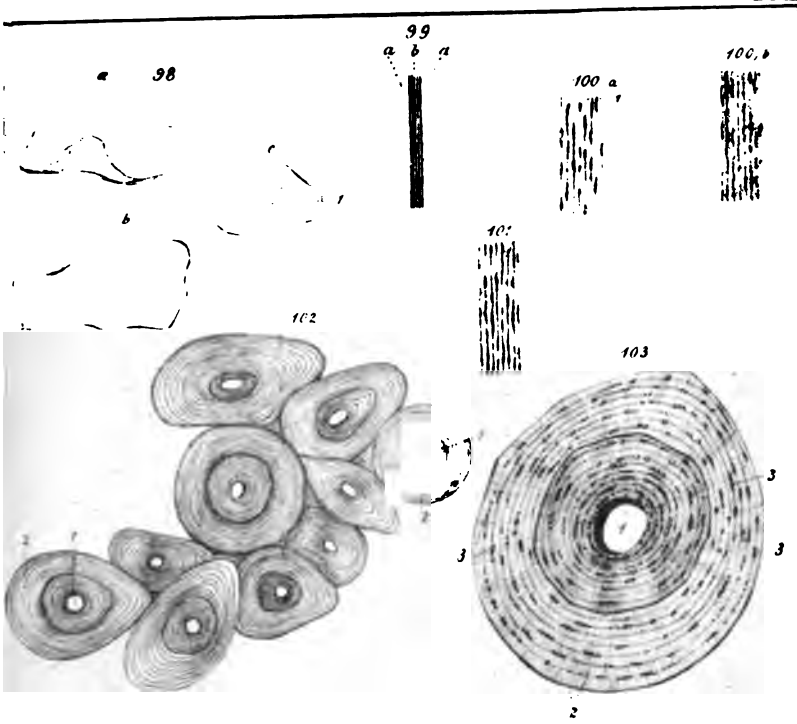
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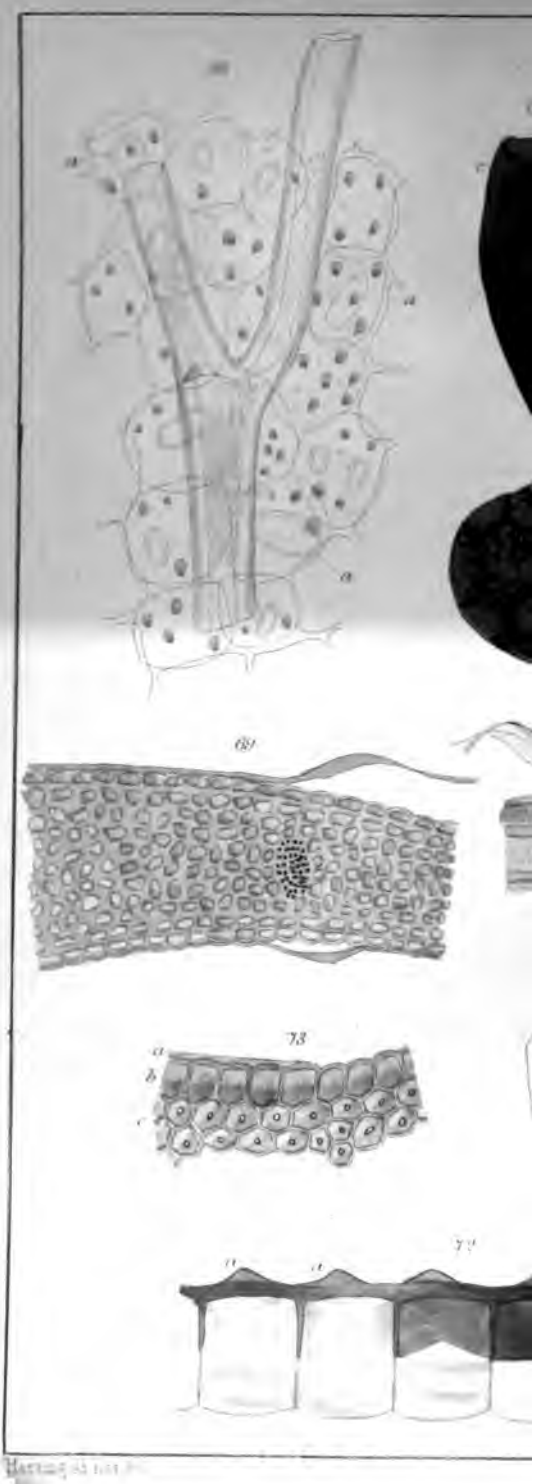
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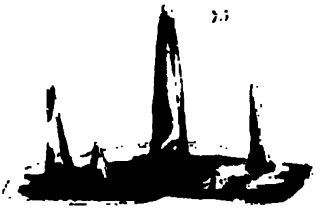

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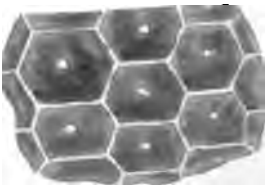

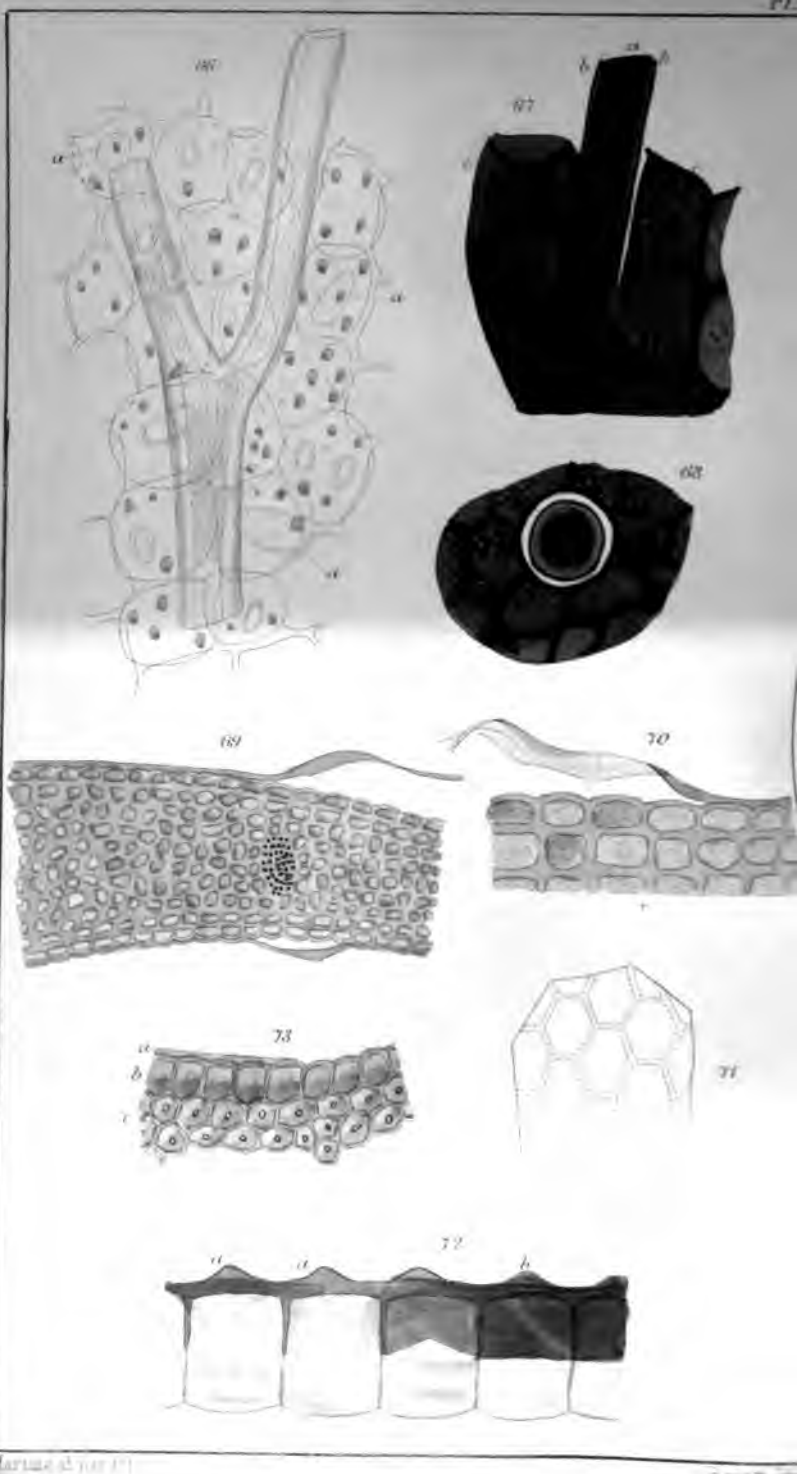
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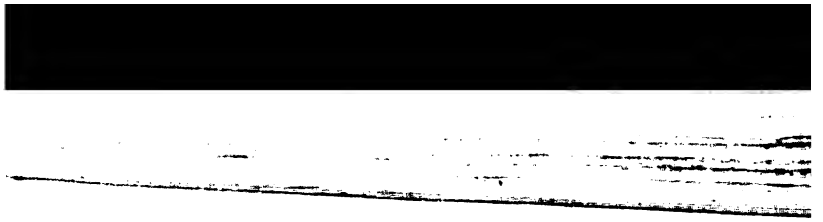

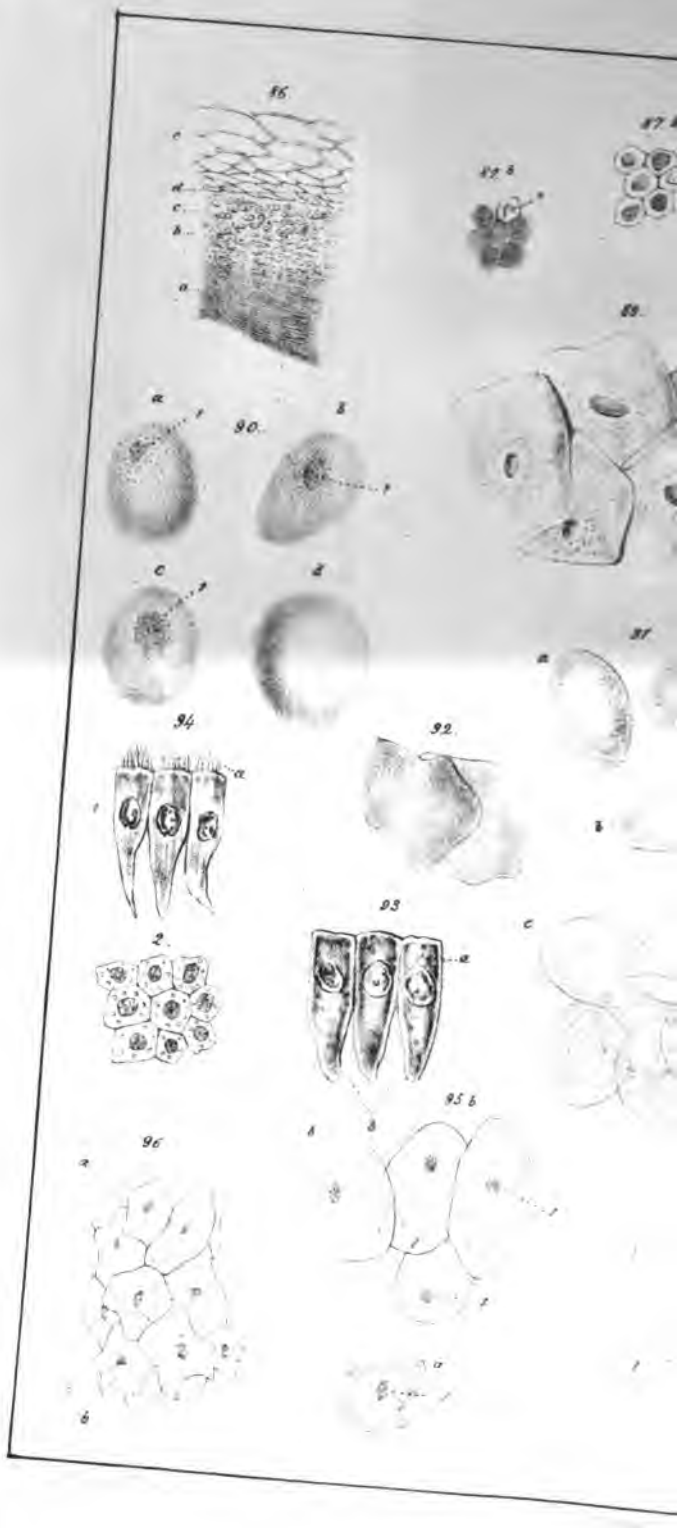
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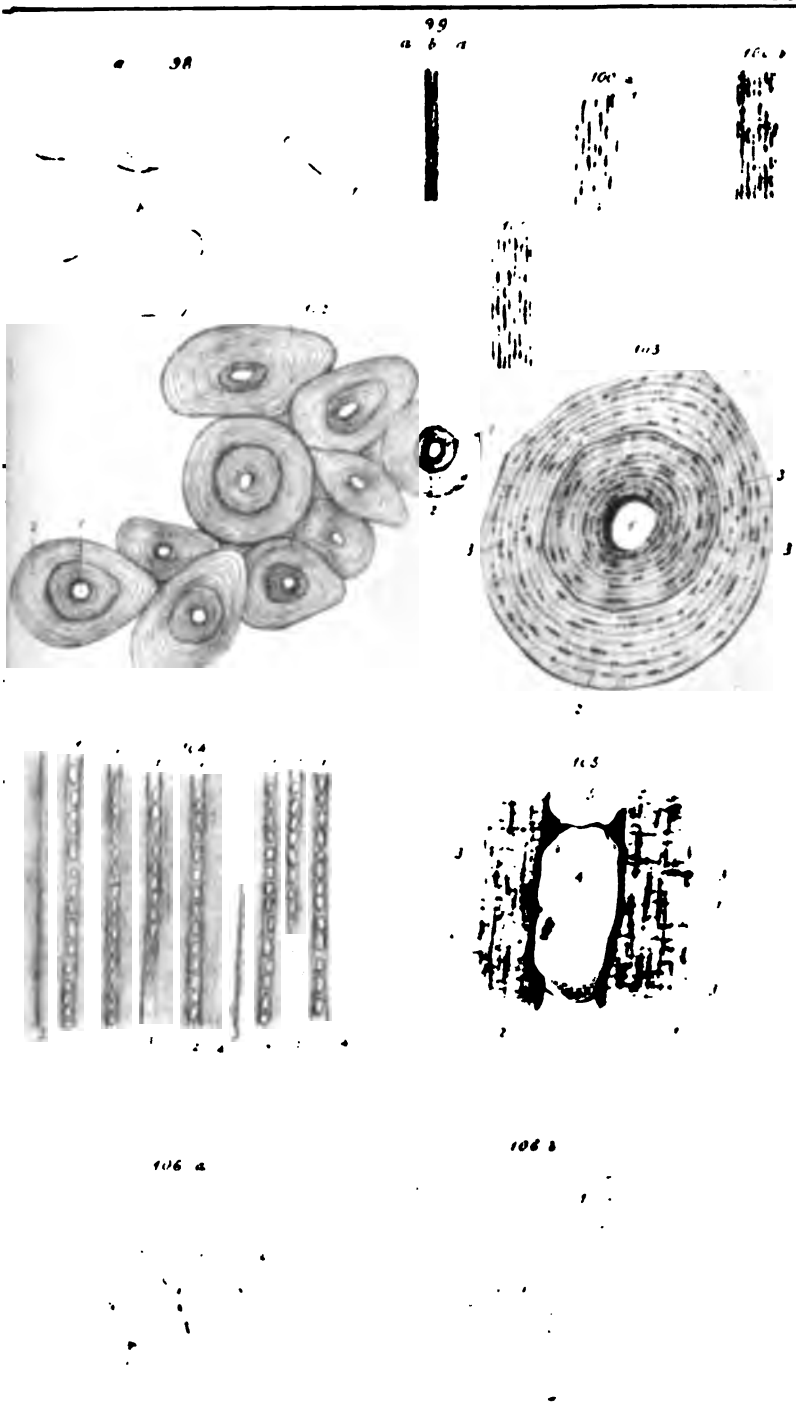

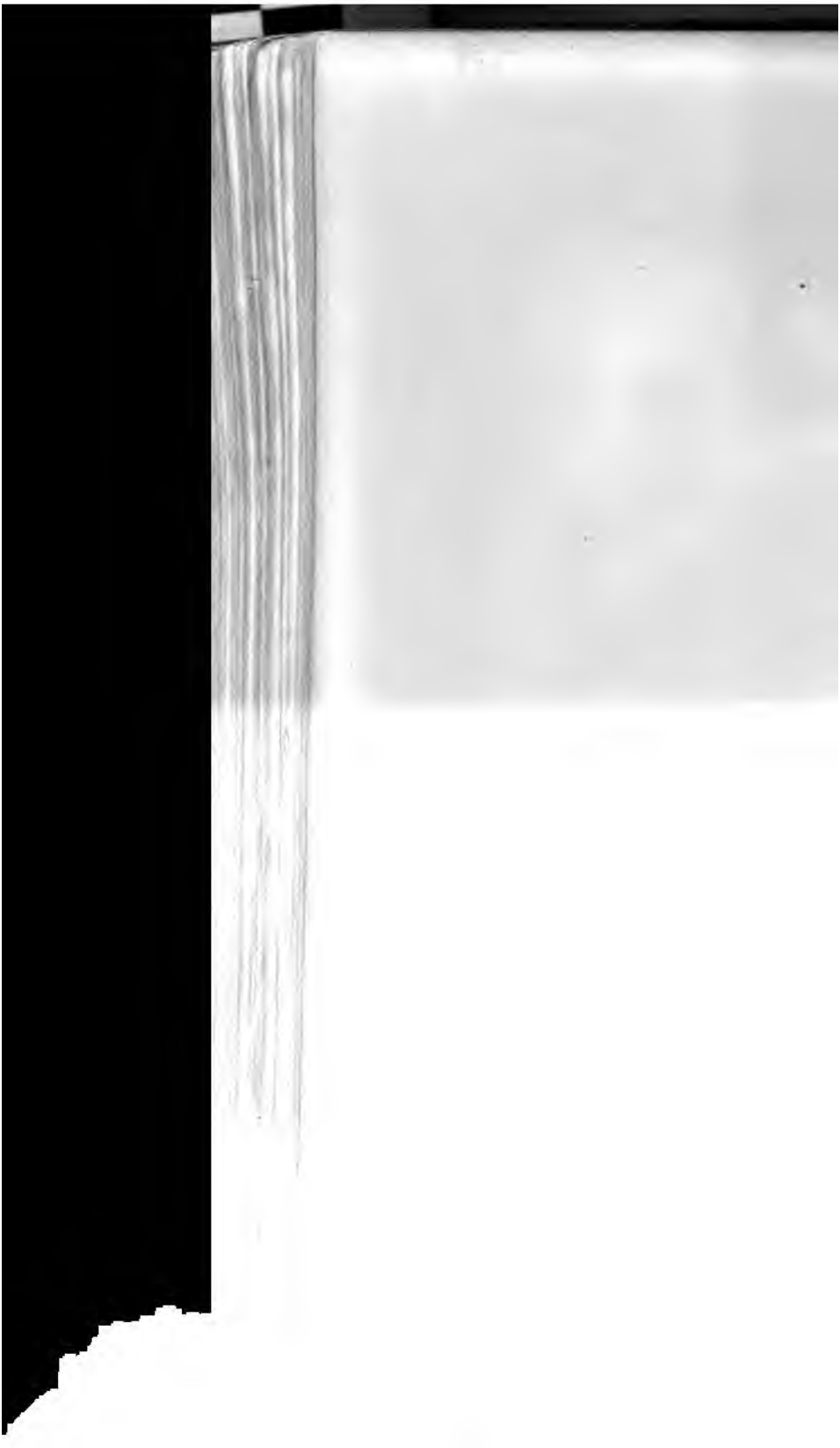

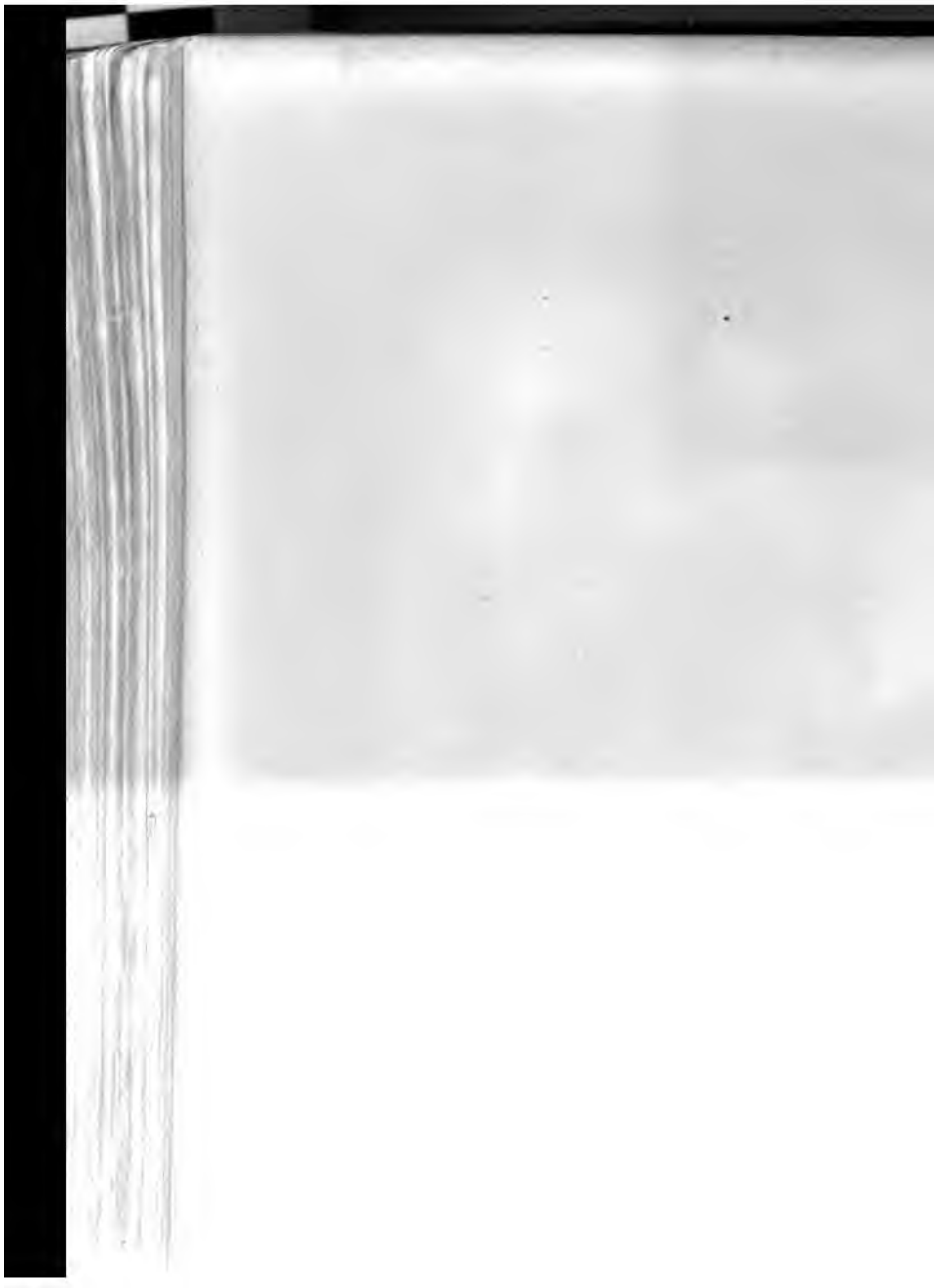

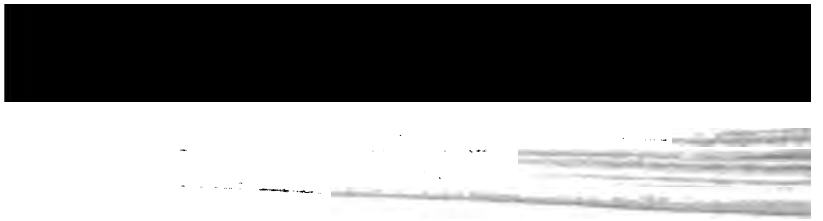

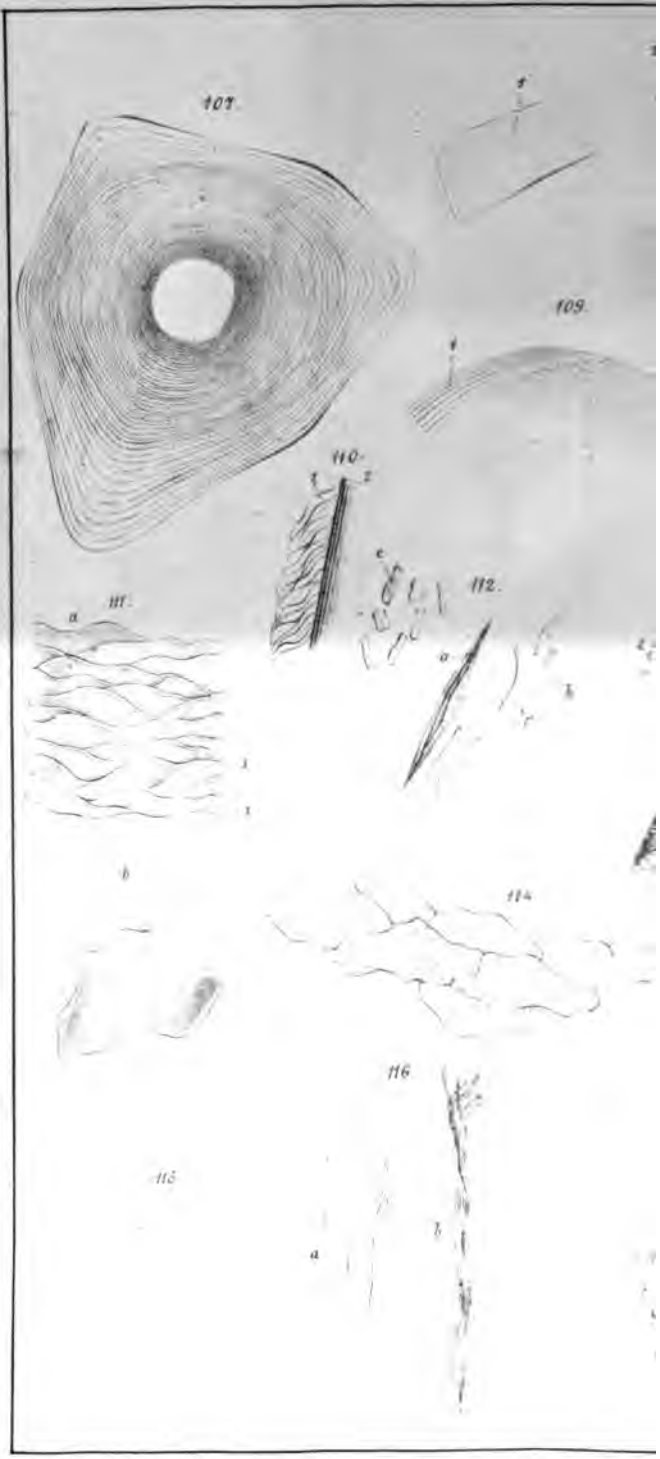
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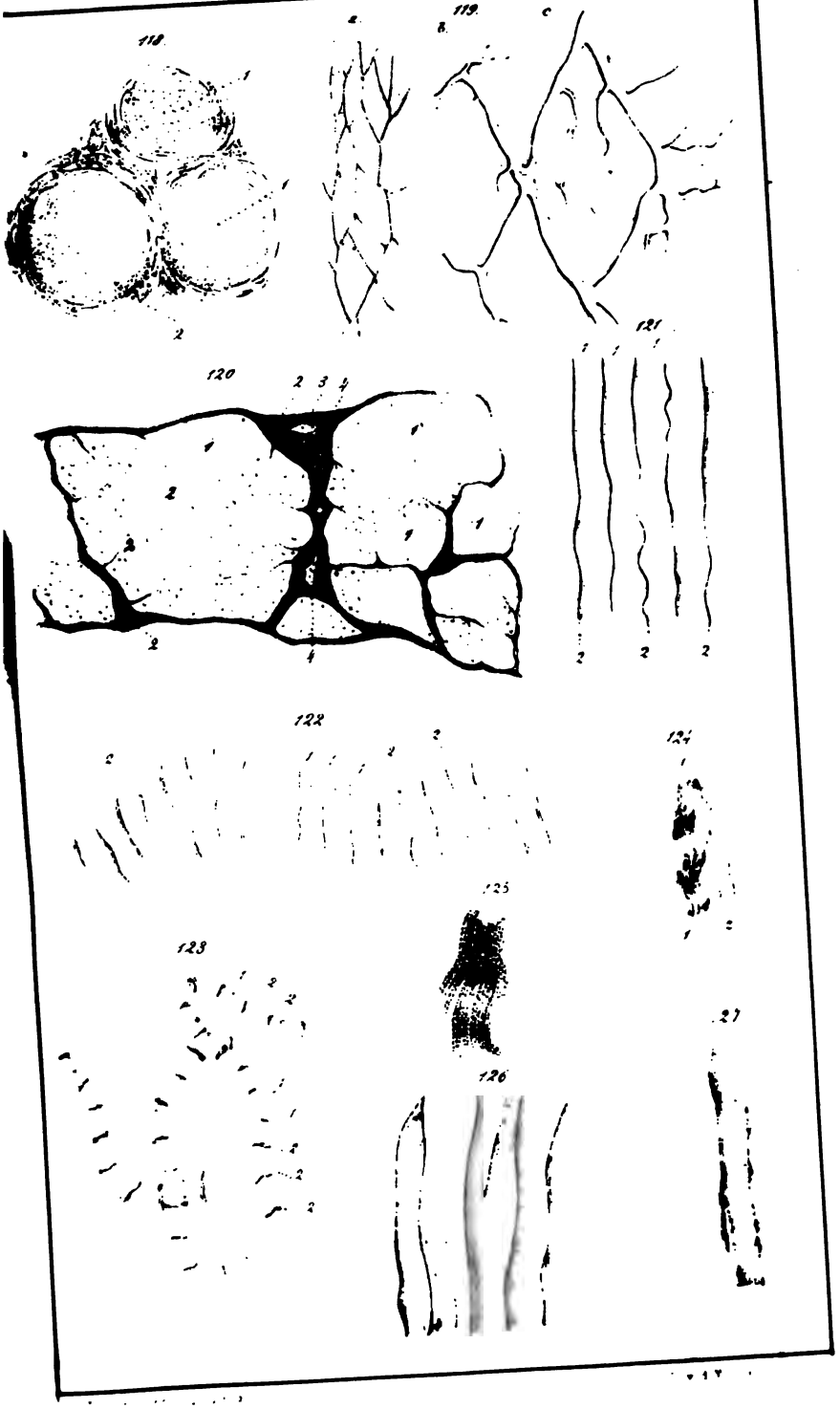
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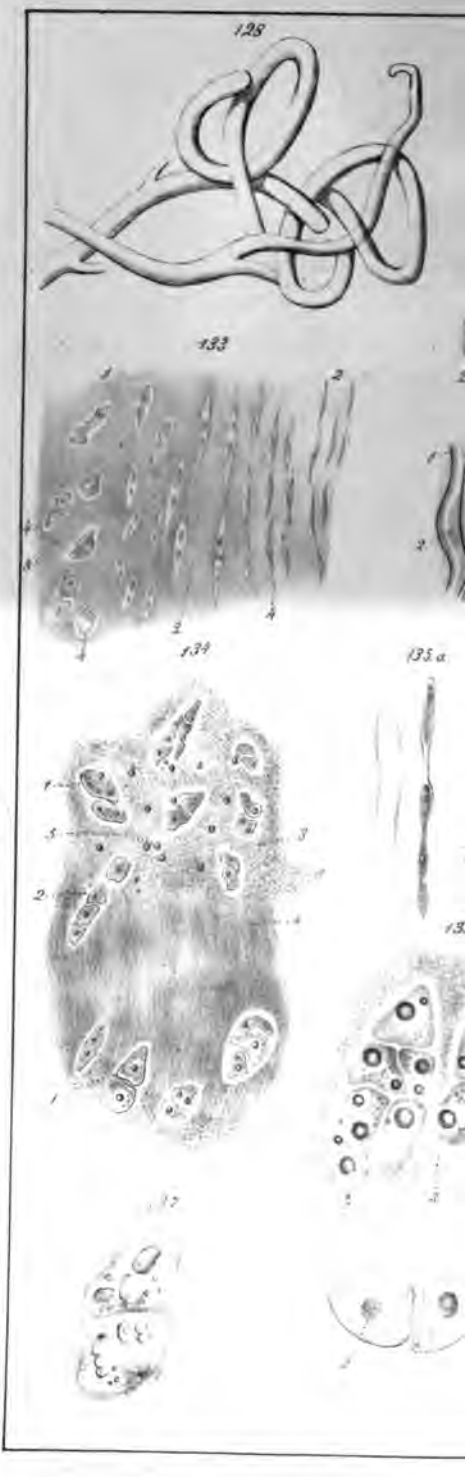
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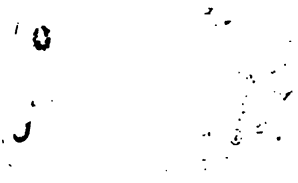

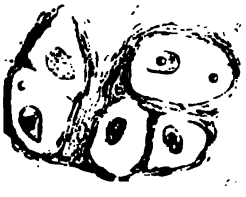

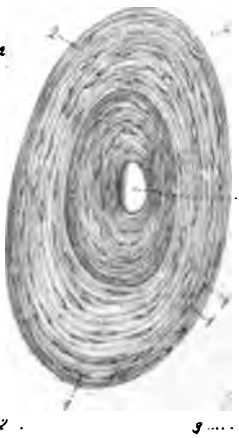

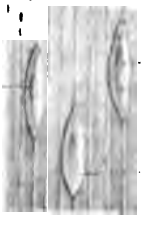

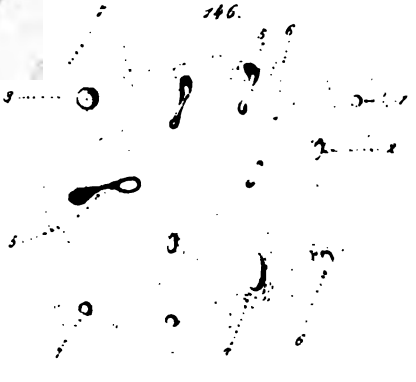

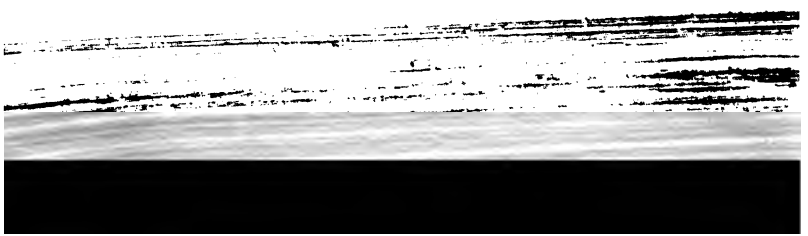

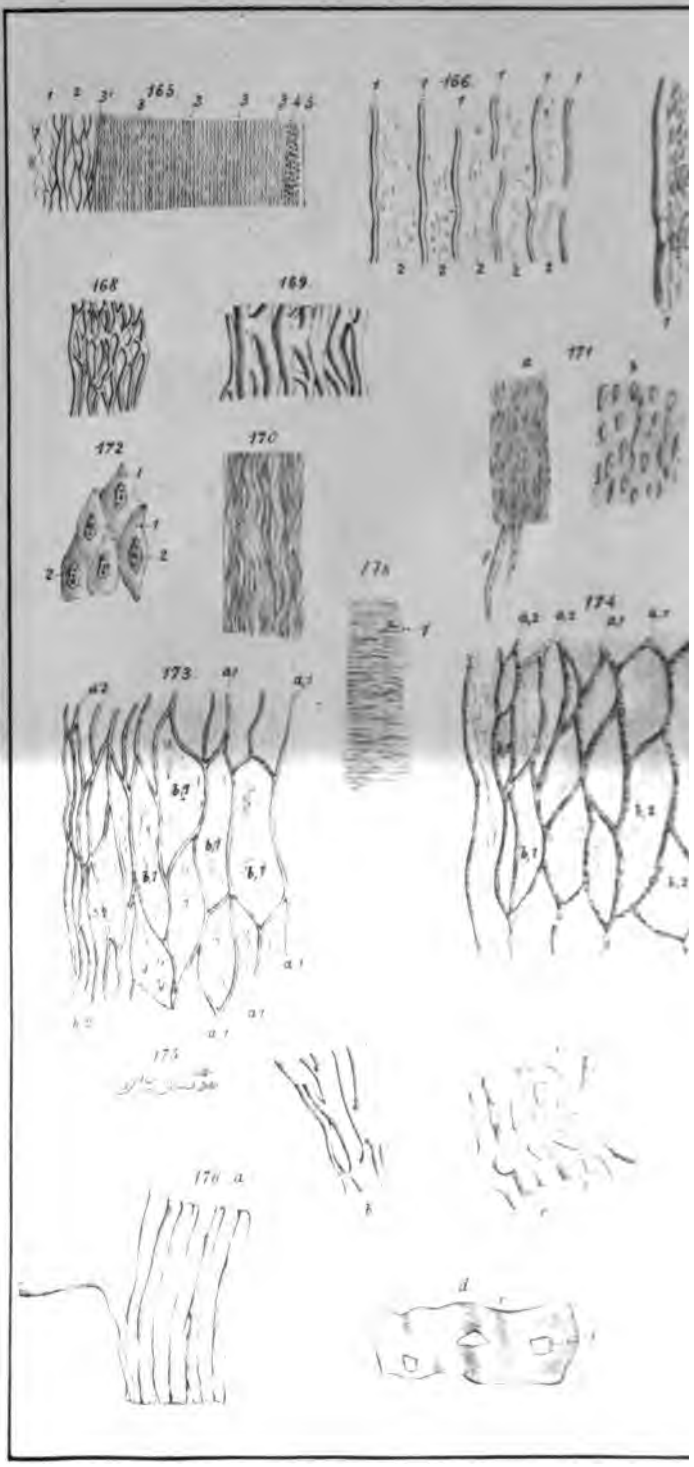
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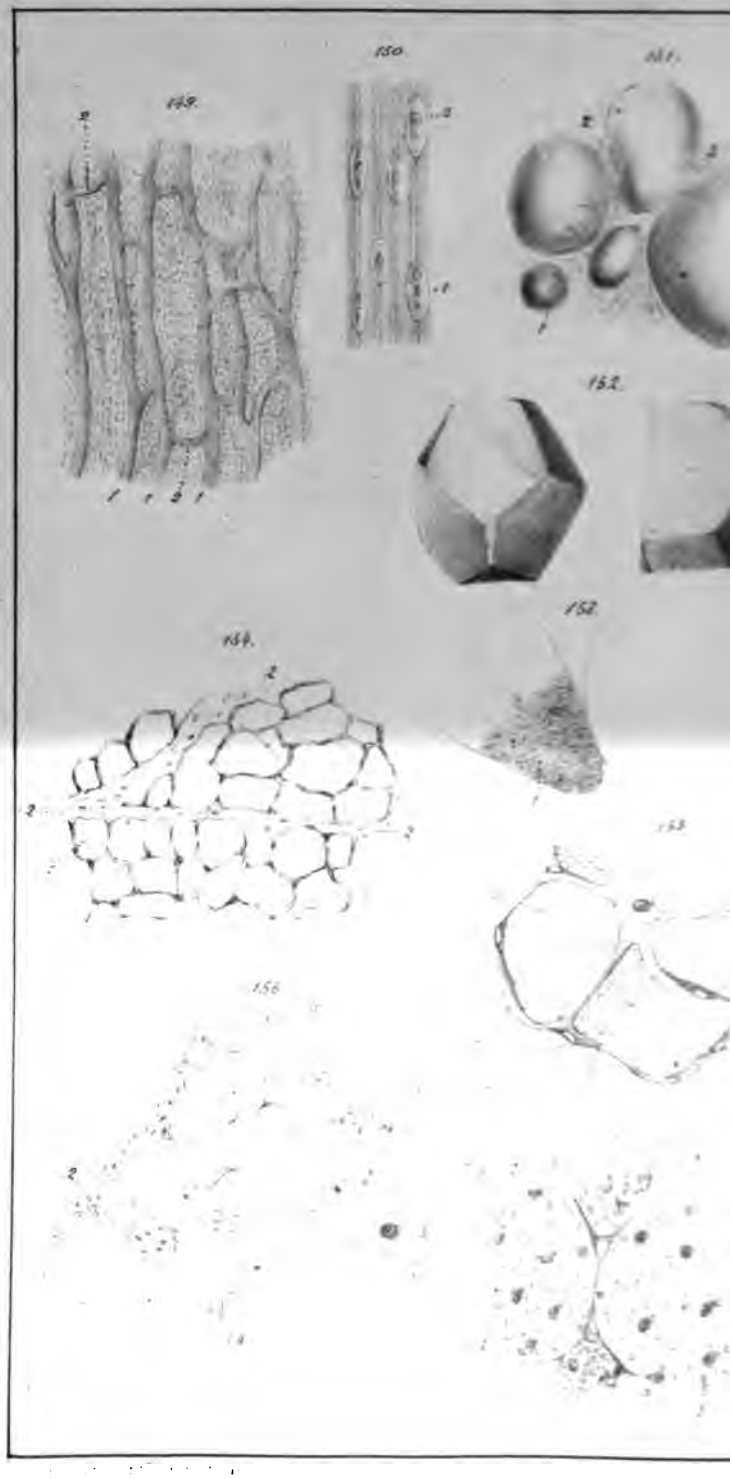
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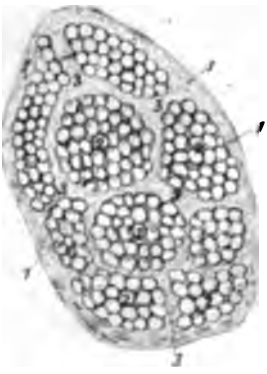

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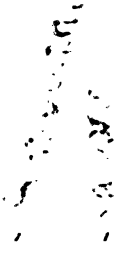

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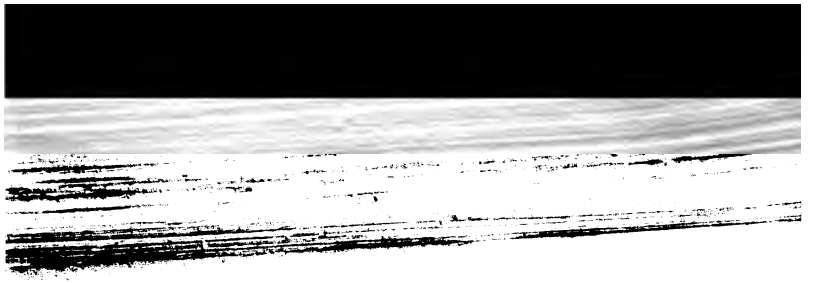

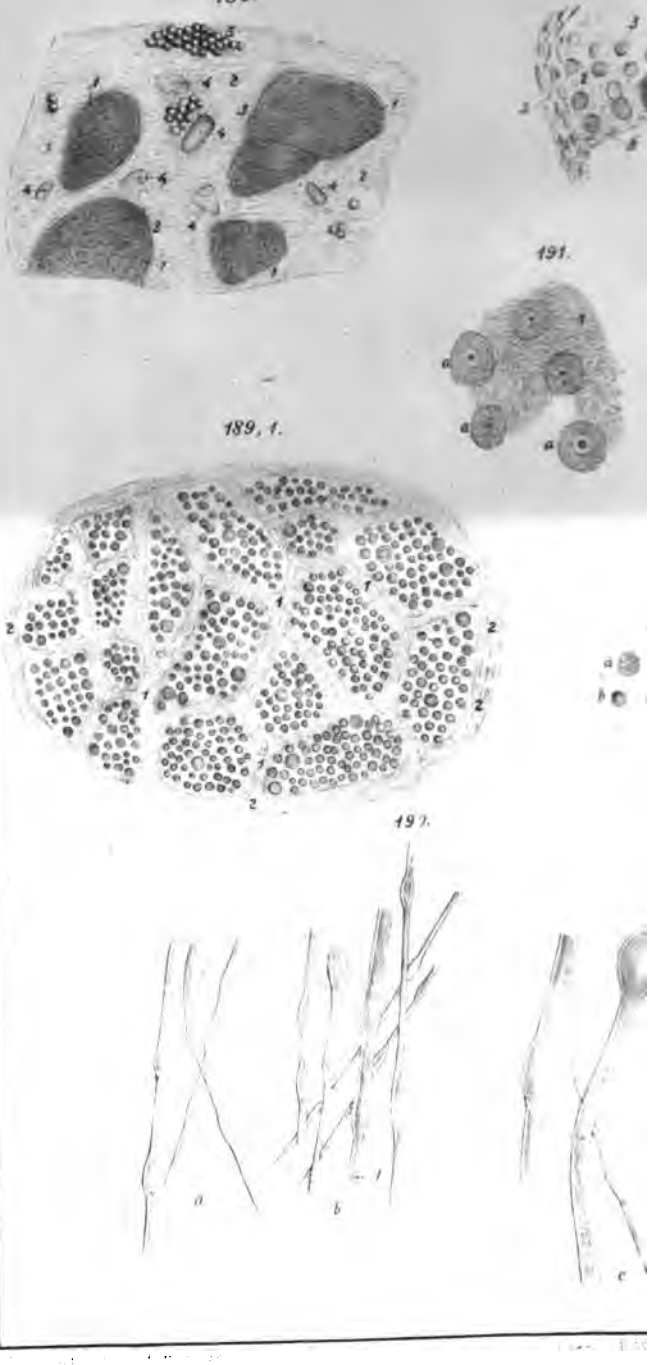
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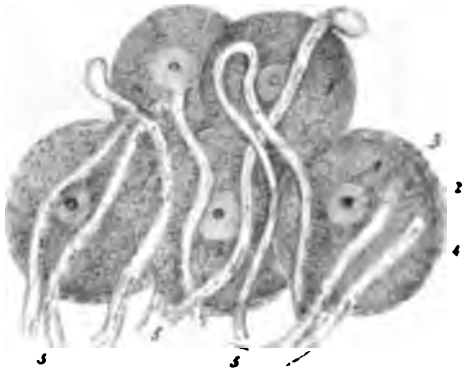

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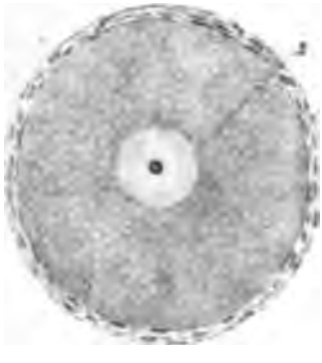

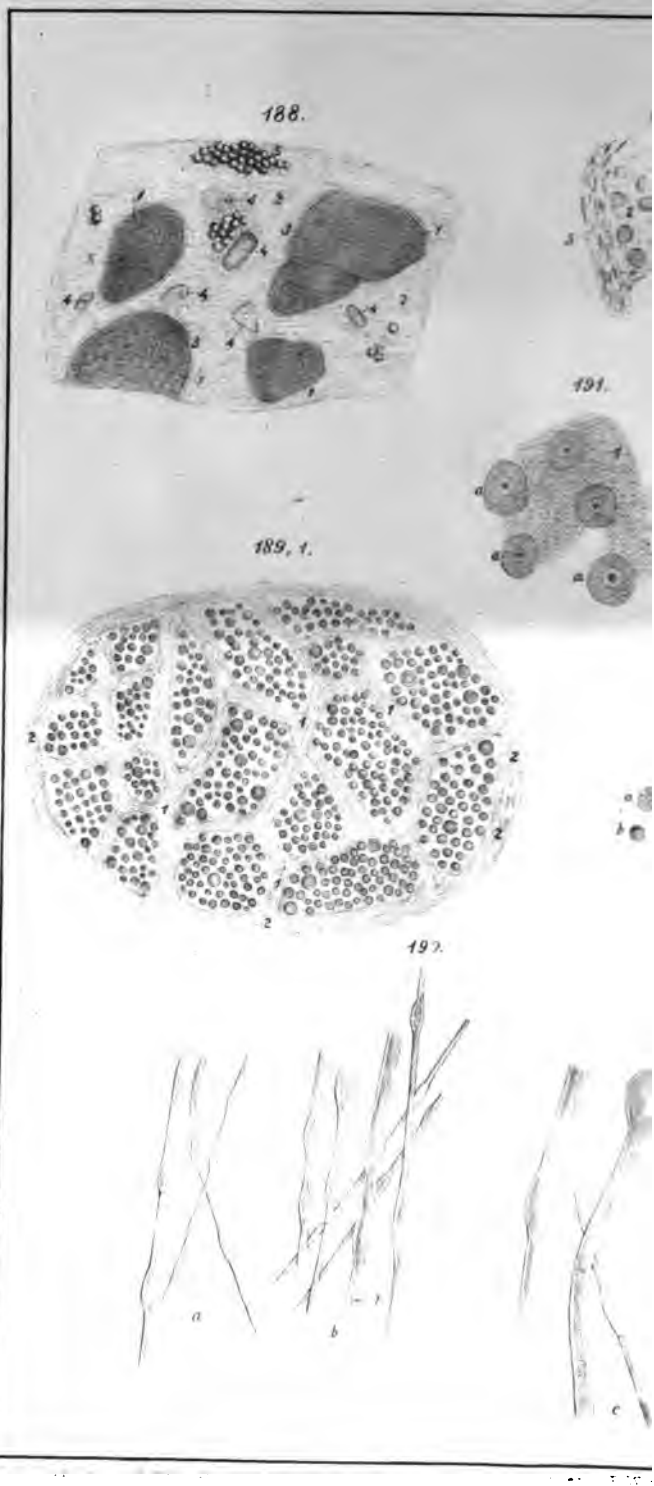
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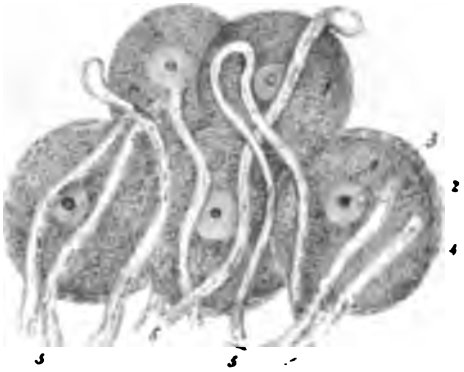

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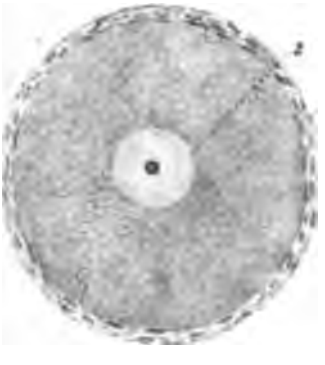

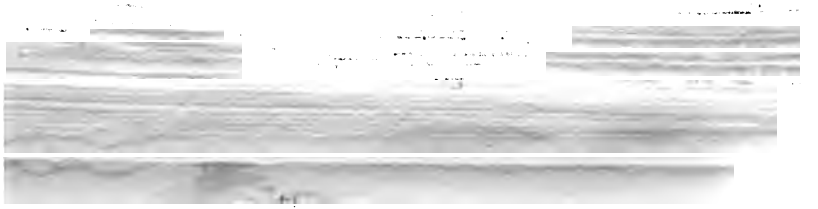

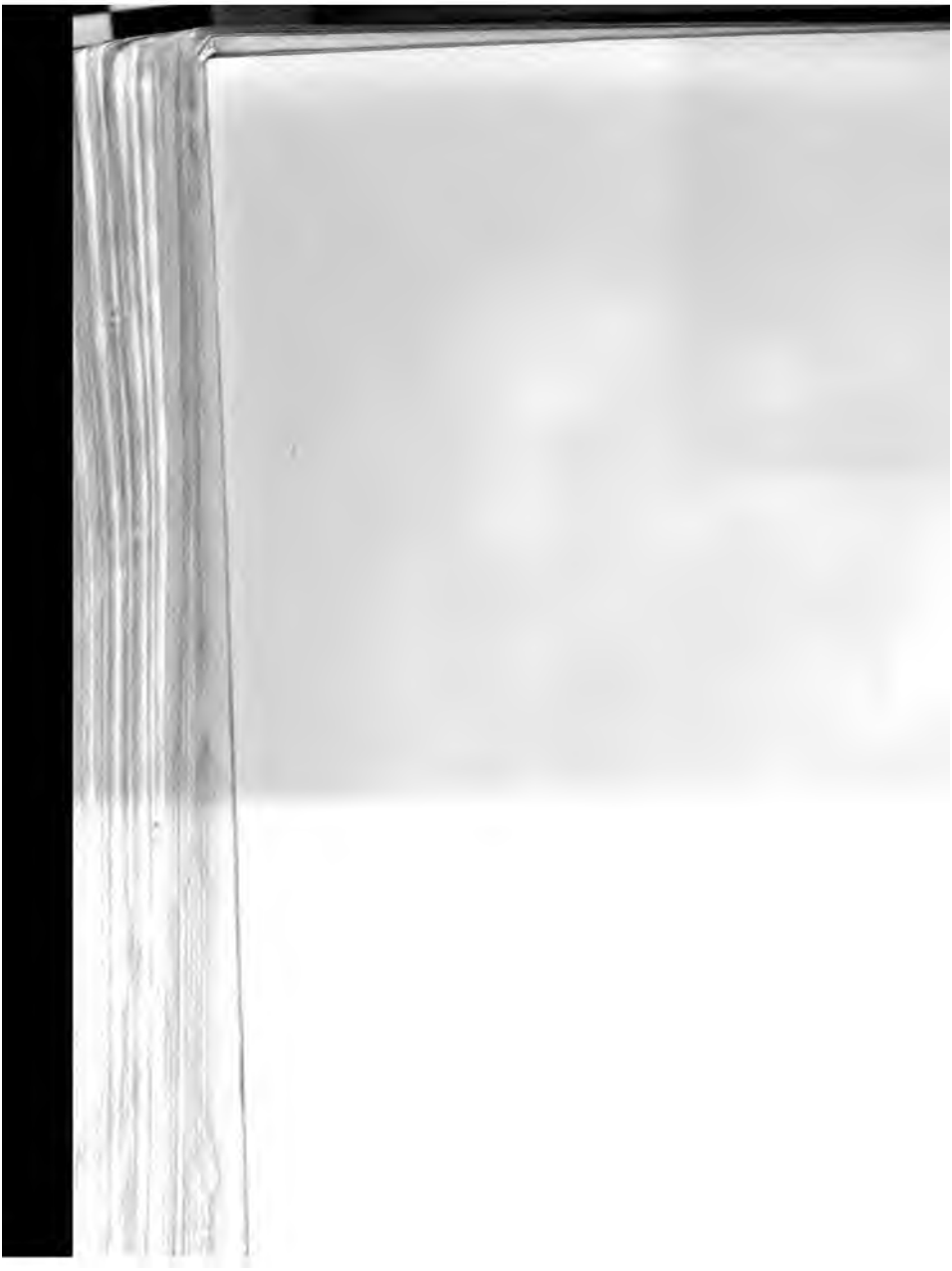

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